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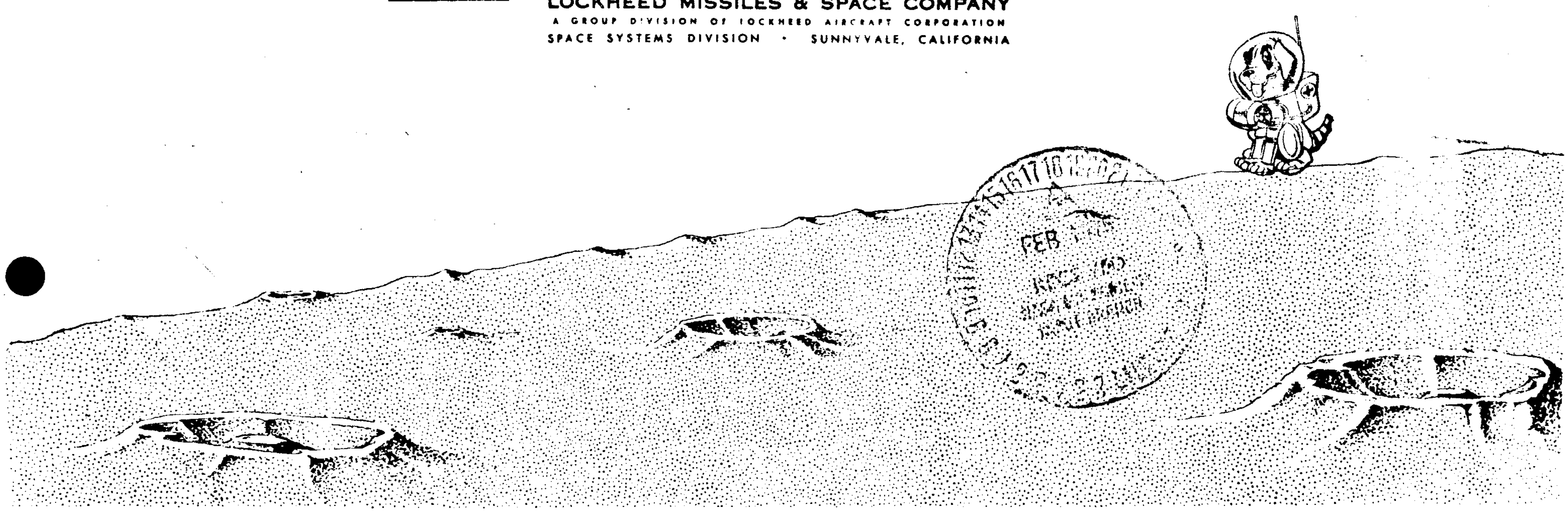
LUNAR MISSION SAFETY AND RESCUE

STUDY CONTRACT NAS9-10969

FINAL BRIEFING

LOCKHEED MISSILES & SPACE COMPANY
A GROUP DIVISION OF LOCKHEED AIRCRAFT CORPORATION
SPACE SYSTEMS DIVISION · SUNNYVALE, CALIFORNIA



LMSC-A984262E

LUNAR MISSION SAFETY AND RESCUE
FINAL PRESENTATION
MARCH 1971

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FOREWORD

This document summarizes results of the "Lunar Mission Safety and Rescue" study, performed for the Manned Spacecraft Center, National Aeronautics and Space Administration, Houston, Texas, under Contract NAS 9-10969. Preparation of this report is specified by the MSC DRL-T-591, Line Item 6, of the subject contract.

CONTENTS

INTRODUCTION

AND

BACKGROUND

STUDY OBJECTIVES

Within the limitations of the present concepts and planning of the Advanced Lunar Missions, the study established the essential guidelines for the enhancement of safety in advanced lunar missions.

STUDY OBJECTIVES

- ESTABLISH SAFETY GUIDELINES FOR ADVANCED LUNAR MISSIONS
- IDENTIFY RESCUE MISSION REQUIREMENTS
- ESTABLISH ESCAPE AND SURVIVABILITY REQUIREMENTS
- DEVELOP RESCUE CONCEPTS AND A RESCUE PLAN

STUDY CONSTRAINTS

This study was limited to a safety analysis of significant hazards that personnel may encounter on the lunar surface and during lunar orbital operations. From this analysis resulted the determination of the necessary safety requirements to obviate these hazards, including preferential mission modes and preventive, remedial, emergency survival, escape, and rescue techniques and requirements, which need to be incorporated into the integrated program plan.

STUDY CONSTRAINTS

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- ANALYSES CONSTRAINED TO LUNAR SPHERE OF INFLUENCE
- ANALYZE OPERATIONS AND INTERFACES OF MAJOR IPP ELEMENTS
- ASSUME DESIGN AND ROUTINE INTERNAL OPERATIONS OF MAJOR IPP ELEMENTS ARE OPTIMIZED AND NO HAZARDS ANALYSES REQUIRED
- NO CLASSICAL RELIABILITY OR PROBABILITY ANALYSES PERFORMED
- PLANNED IPP ELEMENTS ARE USED FOR RESCUE WHERE POSSIBLE
- STUDY RESULTS ARE KEPT GENERAL ENOUGH THAT THE GUIDELINES AND PLAN WILL BE VALID THOUGH IPP ELEMENTS AND OPERATIONS CHANGE

EQUIPMENT ELEMENTS AND USAGE

- Transportation between Earth orbit and lunar orbit
  - Nuclear Shuttle
  - Chemical Shuttle (alternate)
  - Lunar Lander Tug (emergency return)
- Operations in lunar orbit
  - Orbiting Lunar Station
  - Lunar Lander Tug (normal and rescue)
  - Propellant Depot
  - Consumables Capsules
  - Unmanned Satellites (scientific, communications, etc.)
- Transportation between lunar orbit and lunar surface
  - Lunar Lander Tug (normal and rescue)
- Operations on the lunar surface
  - Lunar Lander Tug (normal and rescue)
  - Lunar Surface Base
  - Roving vehicles (normal and rescue)
  - Flying vehicles (normal and rescue)
  - Science equipment (emplaced stations, drills, telescopes, etc.)
  - Support equipment (elec, power, trailers, supply cannisters, etc.)

EQUIPMENT ELEMENTS AND USAGE

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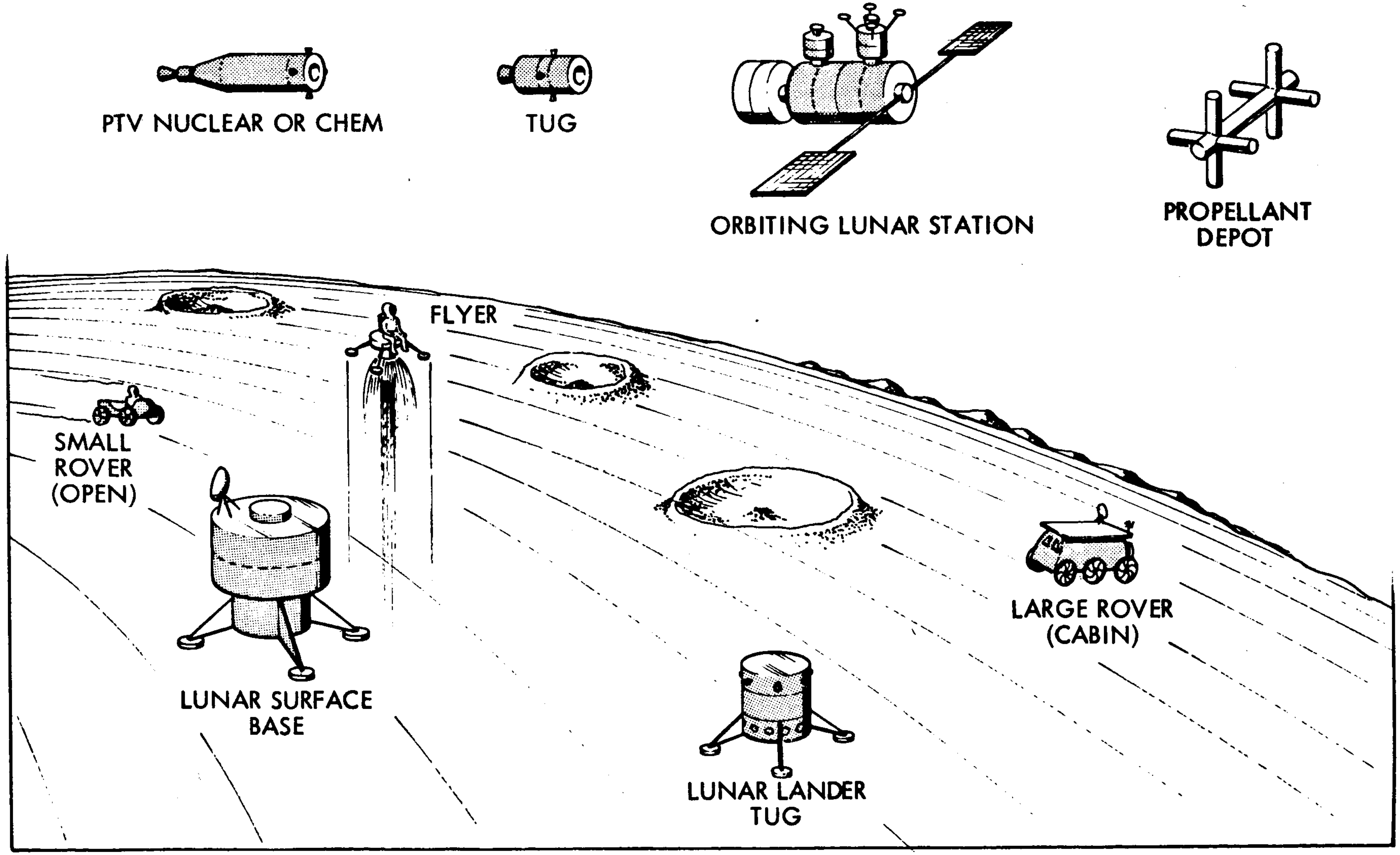

LUNAR MISSION OPERATIONS

Lunar mission operations in orbit and on the surface are listed on the chart. Hazards associated with these operations were examined in the study.

LUNAR MISSION OPERATIONS

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EARTH-MOON SHUTTLE OPERATIONS	ORBITAL OPERATIONS	SURFACE OPERATIONS
TRANSPORT PAYLOAD	RENDEZVOUS & DOCKING	SCIENCE
LUNAR ORBIT INSERTION	SCIENCE	MAINTENANCE
TRANS EARTH INJECTION	MAINTENANCE	TECHNOLOGY & ENGINEERING
RENDEZVOUS & DOCKING	TECHNOLOGY & ENGINEERING	DEPLOYMENT
STATION KEEPING	OPERATIONS BASE	ROVING
CONTINGENCY OPERATIONS	TUG REFUELING	FLYING
	EVA	WALKING
	ORBIT KEEPING & TRANSFER	RESUPPLY
	SATELLITE PLACE & SERVICE	RESCUE
	RESUPPLY	CONTINGENCY OPERATIONS
	RESCUE	
	CONTINGENCY OPERATIONS	

SUMMARY OF STUDY APPROACH

The study was divided into two major tasks. These were:

1. Hazards Analyses leading to safety requirements and recommendations, rescue mission requirements, and safety technology development recommendations.
2. Escape/Rescue Analyses leading to escape/rescue concepts and a lunar mission rescue plan.

SUMMARY OF STUDY APPROACH

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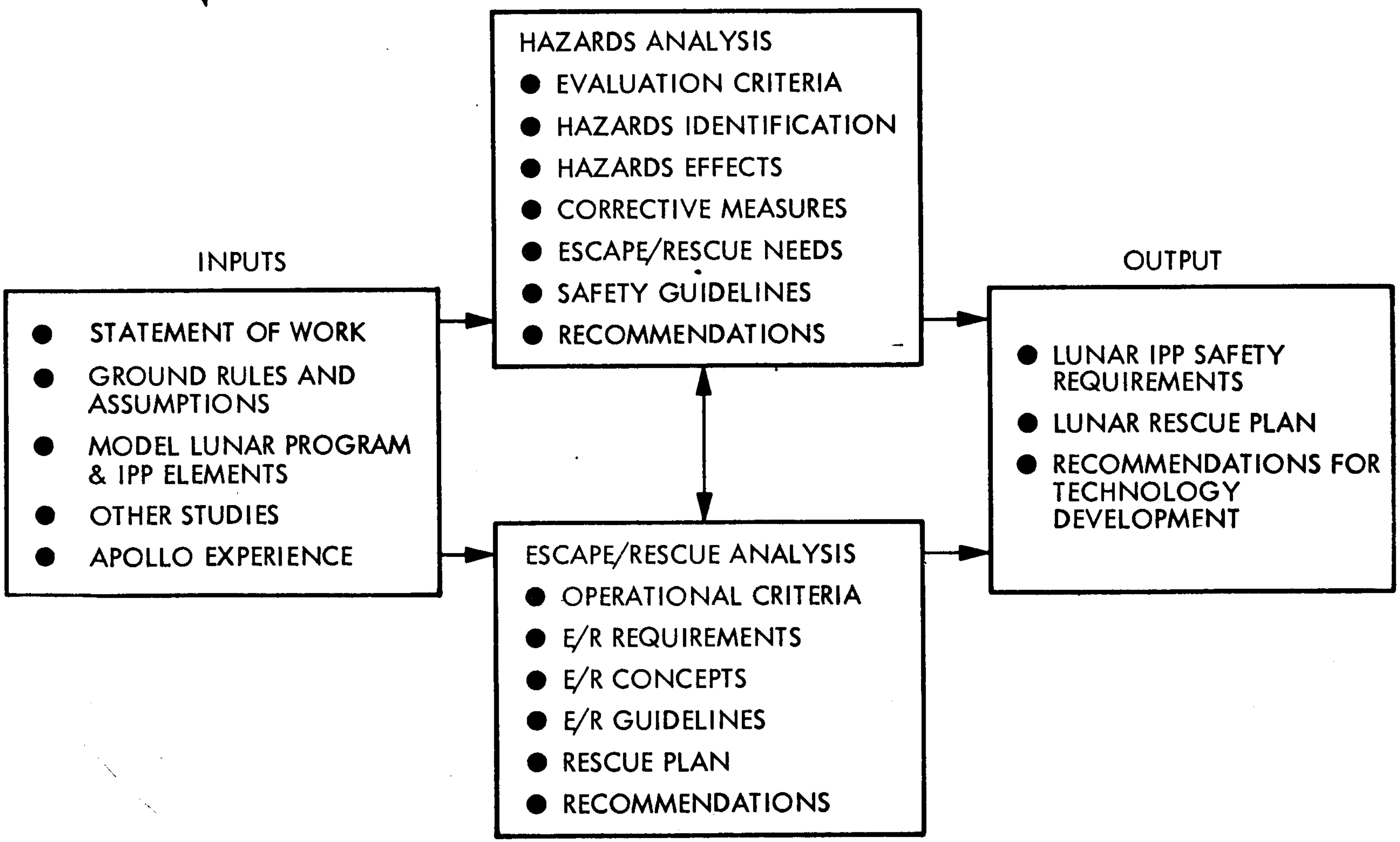

HAZARDS
ANALYSIS
RESULTS

HAZARDS ANALYSIS OBJECTIVES

The objectives of the hazards analysis task were to:

- Determine how safety can be enhanced on the next generation of lunar exploration missions
- Determine the areas in which concentrated safety efforts should provide the greatest safety return
- Show how hazards can be effectively controlled
- Determine preferential mission modes
- Identify conditions and situations requiring rescue.

HAZARDS ANALYSIS OBJECTIVES

- IDENTIFY POTENTIAL HAZARDS
- DETERMINE HAZARDS EFFECTS
- DEVELOP CORRECTIVE MEASURES
- IDENTIFY RESCUE REQUIREMENTS
- ESTABLISH SAFETY GUIDELINES
- IDENTIFY NEED FOR TECHNOLOGY DEVELOPMENT AND ADDITIONAL STUDY

THE HAZARD GROUP DEFINITIONS

1. **Explosion/Implosion** – The sudden and violent disruption of vehicle, shelter, haven or contiguous equipment component integrity.

2. Fire – Slow or rapid combustion of vehicular, habitat, or suit materials capable of sustained burning once ignited.

3. Pressure Excursions – Any non-violent decompression/over-pressure event occurring in vehicle, habitat or suit, outside of established pressure limits.

4. Collison – Impact with natural or man-made objects whether originating from internal (vehicle, shelter) or external sources.

5. Contamination – The presence of an elemental or structured substance, or biological organism, whether toxic or non-toxic, which exceeds specified permissible concentration limits for the surface, fluid or media under consideration.

6. Injury/Illness – Condition in which the health and well-being of the crew or a crew member is impaired or destroyed, due to organic damage or degradation or to biological invasion.

7. Personnel Isolation – Condition or situation wherein a barrier exists between a crewman and his haven of safety.

8. Motion/Accelerations – Situations induced by the movement of personnel, or of space or surface vehicles, whether planned or unplanned.

9. Human Error – Accidental or unintentional departure from established plans or procedures. Impaired awareness of, or misjudgment regarding a situation and a course of action required.

10. Hostile Environment – Exposure to environmental conditions which may be inherently destructive to human life.

11. Radiological Hazards –

    (a) Natural Sources: External electromagnetic radiation, cosmic radiation, solar flares, and by-products of Stellar nuclear reactions.

    (b) Man-Made Sources: Energy radiating equipments, of all types emitting penetrating rays, beams and particles.

12. System or Subsystem Malfunction – The malfunction of system, subsystem, or equipment item, the functional capability of which is critical to the execution of a local or remote operation or activity.

THE HAZARD GROUPS

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1. EXPLOSION/IMPLOSION
2. FIRE
3. PRESSURE EXCURSION
4. COLLISION
5. CONTAMINATION
6. INJURY/ILLNESS
7. PERSONNEL ISOLATION
8. MOTION/ACCELERATIONS
9. HUMAN ERROR
10. HOSTILE ENVIRONMENT
11. RADIOLOGICAL HAZARDS
12. SYSTEM OR SUBSYSTEM MALFUNCTION

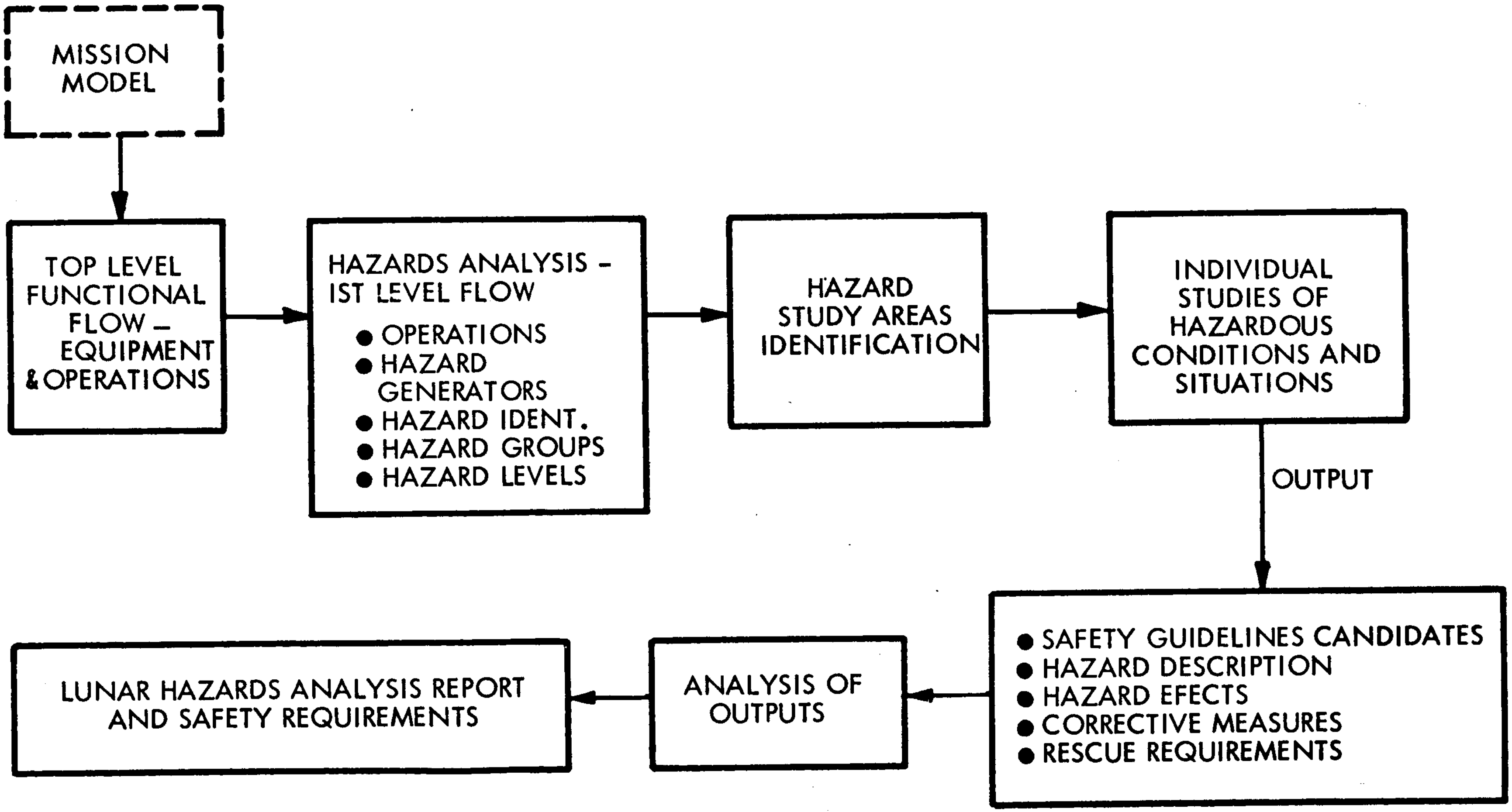
HAZARDS ANALYSIS METHODOLOGY

Working from the task objectives and the defined mission model, the top level functions and operations of lunar exploration elements were described. This was expanded in a first level flow chart to identify potentially hazardous conditions and situations requiring study. A list of hazardous conditions and situations selected for further study was compiled, and the studies carried out. From the individual studies, rescue requirements were identified and candidates for safety guidelines proposed. When the individual studies were complete, a study of the guidelines candidates was made to assess compatibility and feasibility and firm up recommendations to be included in the final report.

The format used for each Hazard Study was:

- Study title
- Introduction
- Assumptions
- Identification of the major hazards –
  - Effects of the hazard
  - Description of alternate corrective measures
  - Escape/rescue requirements
- Data source references
- Summary of safety guidelines candidates

HAZARD ANALYSIS METHODOLOGY



HAZARD STUDY GROUPS

One or more hazard studies were performed for each of the groups shown on the chart. The groups encompass exploration equipment elements, mission operations, mission activities, environmental conditions, and special events.

In the Hazards Analysis Results presentation, only a small cross-section of the subjects studied can be discussed as typical. Those chosen are:

- Prime Transport Vehicles
- Orbiting Lunar Stations
- Lunar Lander Tugs
- Lunar Surface Bases
- EVA Roving Traverses

HAZARD STUDY GROUPS

- PRIME TRANSPORT VEHICLES
- ORBITING LUNAR STATIONS
- ORBITING TUGS AND LANDERS
- LANDERS ON THE LUNAR SURFACE
- PROPELLANT DEPOTS
- LUNAR SURFACE BASES
- ROVING VEHICLES
- FLYING VEHICLES
- PRESSURE CABINS
- SCIENCE EQUIPMENT AND UNMANNED SATELLITES
- ORBITAL EVA
- SURFACE EVA
- CARGO AND EQUIPMENT HANDLING
- COLLISION IN ORBIT
- LIGHTING
- COMMUNICATIONS LOSS
- NATURAL AND MAN-MADE RADIATION
- METEOROIDS
- HAZARDOUS MATERIALS
- HUMAN ERROR

TYPICAL HAZARDS WITH PRIME TRANSPORT VEHICLES

Prime Transport Vehicles (PTV) may be chemical or nuclear powered. The crew compartments may or may not include, or be attached to, separate propulsion modules. In any event the PTV is on an escape trajectory as it approaches and departs the Moon, and loss of propulsion or attitude control capability leads to loss of the crew unless corrective measures are taken.

Additional hazards include:

- Collision with disabled PTV in lunar orbit
- Motion hazard if PTV fails with excessive angular rates
- Radiation hazard with disabled PTV that is nuclear powered

TYPICAL HAZARDS-PTV

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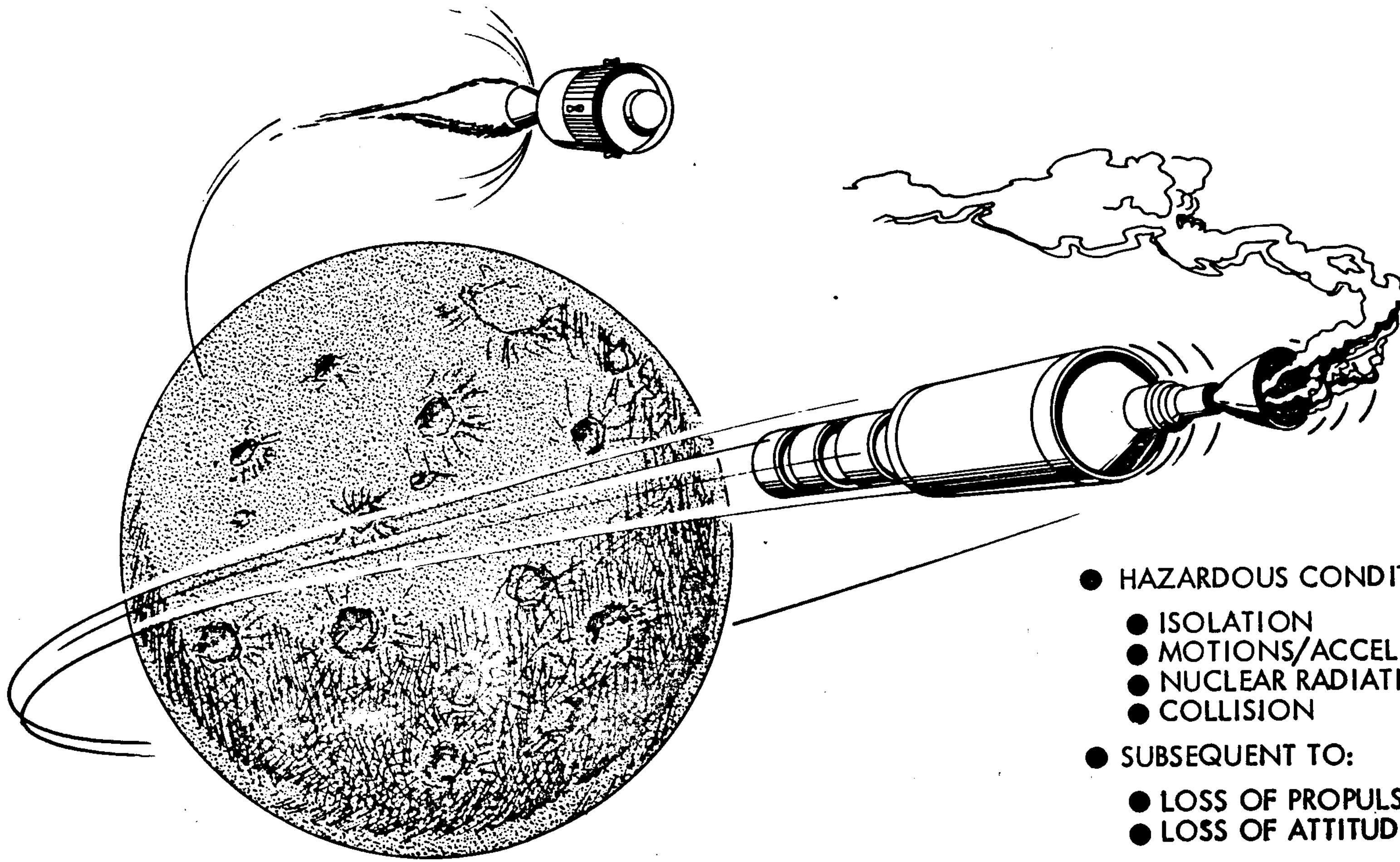

- HAZARDOUS CONDITIONS:
  - ISOLATION
  - MOTIONS/ACCELERATIONS
  - NUCLEAR RADIATION
  - COLLISION
- SUBSEQUENT TO:
  - LOSS OF PROPULSION
  - LOSS OF ATTITUDE CONTROL

TYPICAL SAFETY GUIDELINES FOR PRIME TRANSPORT VEHICLES

- Crew modules, serving essentially as replacement-crew delivery shelters, shall have the capability (as a minimum) to quickly separate and move away from a disabled (stable or tumbling) prime transport vehicle, provide a delta velocity of approximately 1000 ft/sec to achieve an elliptical lunar orbit, and maintain communications (beacon and voice), life support, and coarse attitude while awaiting rescue.
- Prime transport vehicles, whether chemical or nuclear powered, shall not be brought into the same or intersecting orbit with other operational elements such as an orbiting lunar station, and shall always operate from a higher orbital altitude.
- Each manned vehicle in lunar orbit shall be constantly monitoring other traffic, emergencies, or malfunctions that could present a hazard and shall have the ability to maneuver to avoid collision.
- Any derelict vehicle is an unsafe lunar orbit must be captured and either repaired or disposed of by placing it in a safe lunar orbit, returning it to Earth orbit, or injection to heliocentric orbit.
- Rescue crewmen shall not approach a tumbling nuclear vehicle unless protected by a specially prepared and radiation shielded vehicle.
- The crew of a space vehicle shall be able to assume manual control of vehicle attitude in order to avoid or stop tumbling.
- Nuclear PTV's shall not be placed on a free Earth return or lunar surface impact trajectory.

TYPICAL CORRECTIVE MEASURES-PTV

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- FAIL-OP., FAIL-OP., FAIL-SAFE PROPULSION AND ACS
- TWO TUGS ON INITIAL OLS MANNING
- CREW COMPARTMENT SEPARATION AND ESCAPE CAPABILITY
- STAND-BY RESCUE VEHICLE IN LUNAR ORBIT
- MEANS TO STOP ROTATION AND DISPOSE OF DERELICT
- TRAFFIC MONITORING TO AVOID COLLISION
- NON-COINCIDENT, NON-INTERSECTING ORBITS

TYPICAL ESCAPE/RESCUE REQUIREMENTS FOR PRIME TRANSPORT VEHICLES

The most demanding escape/rescue situations for a prime transport vehicle are intercept and removal of a crew on an escape trajectory, and escape from a nuclear powered vehicle with uncontrolled angular motion.

TYPICAL ESCAPE/RESCUE REQUIREMENTS-PTV

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- MAY BE ON AN ESCAPE TRAJECTORY
- MAY BE NUCLEAR OR CHEMICAL
- MAY BE STABLE OR ROTATING
- PAYLOAD MAY OR MAY NOT INCLUDE TUG VEHICLE

TYPICAL HAZARDS WITH ORBITING LUNAR STATIONS

Orbiting Lunar Stations (OLS) may vary in size, function, crew size, power source, and type and numbers of supporting vehicles such as space tugs. One of the more serious hazards facing the OLS, or any crew compartment, is sudden loss of cabin atmosphere while crewmen are in shirtsleeves.

TYPICAL HAZARDS-OLS

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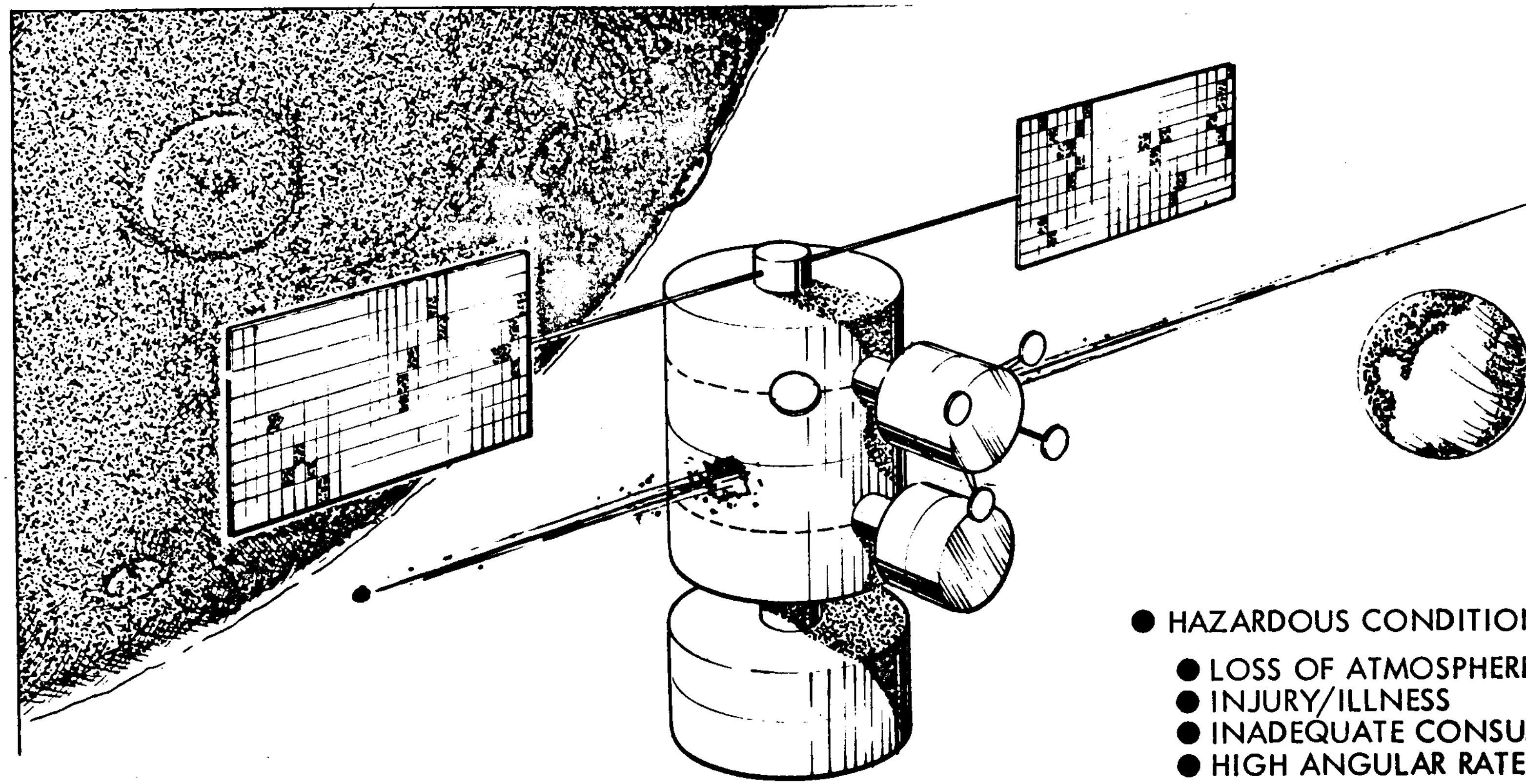

- HAZARDOUS CONDITIONS:
  - LOSS OF ATMOSPHERE
  - INJURY/ILLNESS
  - INADEQUATE CONSUMABLES
  - HIGH ANGULAR RATE
- SUBSEQUENT TO:
  - FIRE
  - EXPLOSION
  - COLLISION
  - METEOROID PUNCTURE
  - ACS FAILURE
  - CONTAMINATION

TYPICAL SAFETY GUIDELINES FOR ORBITING LUNAR STATIONS

- Each crew cabin shall have more than one pressurized compartment capable, at least in an emergency, of supporting the crew. Hatches to interconnecting passageways or airlocks shall be kept open at all times, but quickly sealable in an emergency.
- Each crew cabin shall provide oxygen masks and emergency pressure garments, 2-gas and independent of ECS, at each crew station; pressure suits and PLSS units for each crew member; and immediate use of one or more of these or escape to a separate compartment following explosion, fire, loss of pressure, or detection of contaminants in the atmosphere.
- Where multiple primary pressure compartments are provided in a system, crew members shall not normally all occupy one compartment at one time.
- Each orbiting lunar station shall have docked to it, or in the immediate vicinity, and immediately accessible, space tug vehicles with crew compartments, propulsion modules, and instrument units capable of housing and supporting the entire remaining station crew.
- High pressure gas storage bottles, pyrotechnics, and hazardous experimental devices shall be separated from the main cabin of an orbiting lunar station and from critical subsystems components by enclosing in compartments vented to space and structures designed to control an explosion or fire.
- Attitude control thrusters for space vehicles shall be designed to fail "off" to prevent excessive angular rates from developing.
- Space vehicles shall be provided with backup or emergency attitude stabilization system to arrest tumbling and allow repair or capture by an assisting vehicle.

TYPICAL CORRECTIVE MEASURES-OLS

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- MULTIPLE PRESSURIZED COMPARTMENTS
- EMERGENCY PRESSURE GARMENTS
- EMERGENCY OXYGEN MASKS
- PRESSURE SUIT FOR EACH CREWMAN
- TUGS DOCKED OR AVAILABLE
- ALTERNATE ESCAPE ROUTES
- ACS REDUNDANT AND FAIL-SAFE
- BACKUP AND EMERGENCY CONSUMABLES
- CONTAMINANT MONITORING AND CONTROL
- FIRST AID

TYPICAL ESCAPE/RESCUE REQUIREMENTS FOR ORBITING LUNAR STATIONS

Escape/Rescue requirements for an orbiting lunar station should, in general, be less demanding than for other lunar vehicles, assuming safety guidelines are observed. Larger crews are available for aid, several pressurized compartments are available, and tugs are docked or near at hand.

TYPICAL ESCAPE/RESCUE REQUIREMENTS-OLS

LOCKHEED

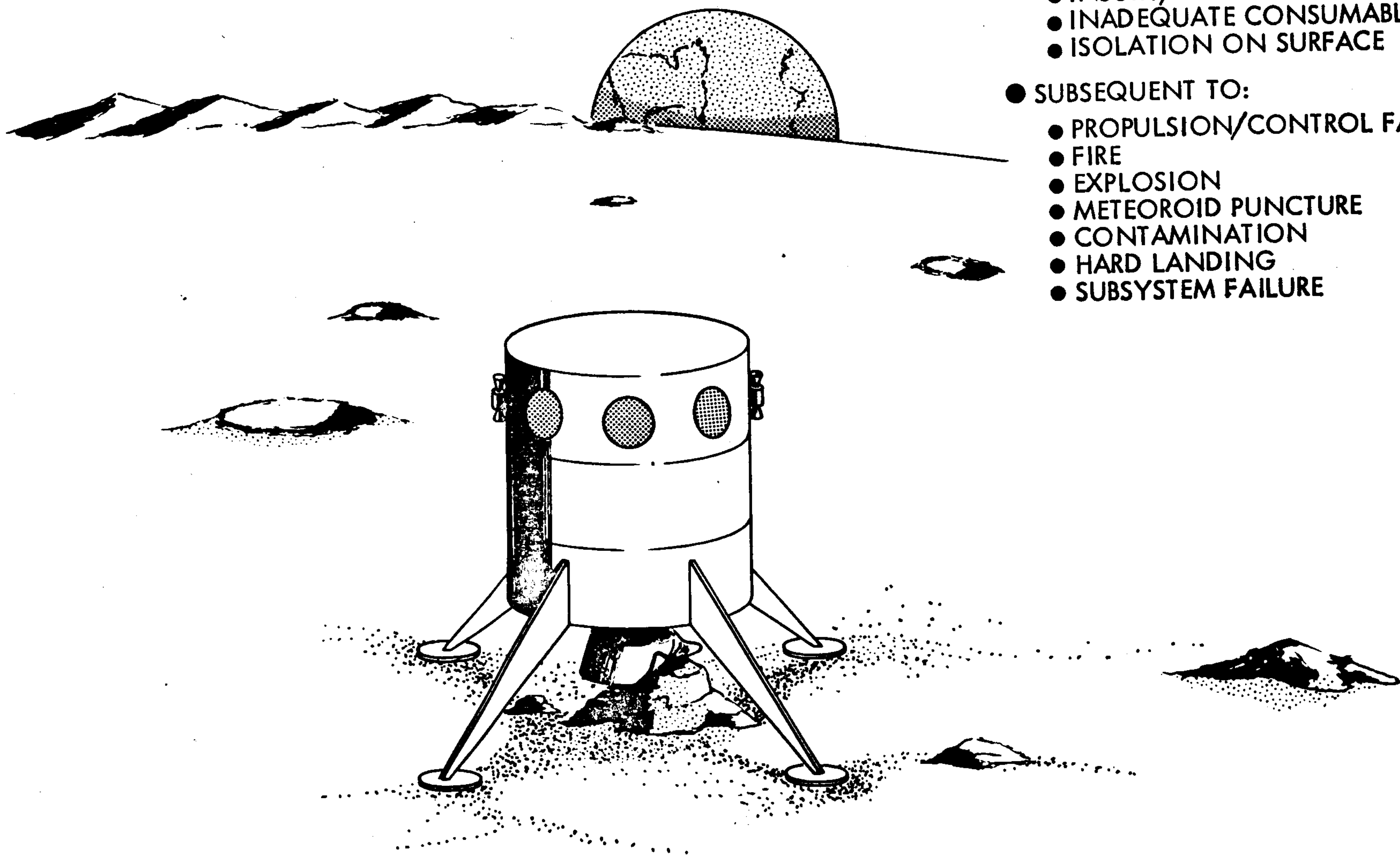
- ORBIT ASSUMED 60 NM CIRCULAR
- CREWMEN MAY BE INCAPACITATED
- MEDICAL AID MAY BE NEEDED
- EVACUATION TO EARTH ORBIT MAY BE NECESSARY
- STATION MAY HAVE ANGULAR ROTATION
- CREW MAY BE IN SHIRTSLEEVES OR PRESSURE SUITS
- CABIN MAY BE PRESSURIZED OR EVACUATED

TYPICAL HAZARDS WITH LUNAR LANDER TUGS

The Lunar Lander Tug (LLT) passes through a critical phase during landing and ascent wherein failure of propulsion or attitude control results in loss of the vehicle. On the surface the tug is vulnerable because the crew is small, no back-up vehicle is nearby, and rescue assistance may take hours or days to arrive.

TYPICAL HAZARDS—LLT

- HAZARDOUS CONDITIONS
  - DESCENT/ASCENT FAILURES
  - LOSS OF ATMOSPHERE
  - INJURY/ILLNESS
  - INADEQUATE CONSUMABLES
  - ISOLATION ON SURFACE
- SUBSEQUENT TO:
  - PROPULSION/CONTROL FAILURE
  - FIRE
  - EXPLOSION
  - METEOROID PUNCTURE
  - CONTAMINATION
  - HARD LANDING
  - SUBSYSTEM FAILURE



TYPICAL SAFETY GUIDELINES FOR LUNAR LANDER TUGS

- Two independent reaction control systems shall be provided on each manned tug.
- The crew of a manned space vehicle shall be provided the capability for manual control of each RCS thruster separately.
- No single function failure of any system or subsystem on board a space vehicle shall result in loss of capability to control attitude and velocity of that vehicle.
- The critical nature of lunar lander tug decent and ascent maneuvers demands special attention to reliability, redundancy, backup, fail-safe, manual override, propellant reserves, and control authority considerations, in all critical functions and subsystems associated with control of velocity and attitude.
- The pilot of a lunar lander tug must be able to assume manual attitude control at any time.
- The crew compartment of a solo lunar lander tug on the lunar surface must be provisioned to support the crew for a period of time following a planned return to orbit until a rescue mission can be accomplished. This time is estimated to be 14 Earth days.
- The lunar lander tug must be flyable by crew members in pressurized space suits.
- Standard operating procedures shall require that crew members, on EVA traverse from a solo lunar lander tug, return to base without delay following notification of an emergency at the tug.

TYPICAL CORRECTIVE MEASURES-LLT

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- EMERGENCY PRESSURIZED COMPARTMENT
- EMERGENCY PRESSURE GARMENTS
- EMERGENCY OXYGEN MASKS
- PRESSURE SUIT FOR EACH CREWMAN
- FAIL-OP., FAIL-OP., FAIL-SAFE PROPULSION & ACS
- BACKUP AND EMERGENCY CONSUMABLES
- CONTAMINANT MONITORING AND CONTROL
- TUG OPERABLE IN PRESSURE SUITS
- FIRST AID

TYPICAL ESCAPE/RESCUE REQUIREMENTS FOR A LUNAR LANDER TUG

A solo Lunar Lander Tug mission to the lunar surface presents a higher risk of need for a rescue mission than do orbital vehicles or a large surface base. At the same time, rescue is made more difficult by the constantly changing physical relationships between the surface base and rescue vehicles in lunar orbit.

TYPICAL ESCAPE/RESCUE REQUIREMENTS-LLT

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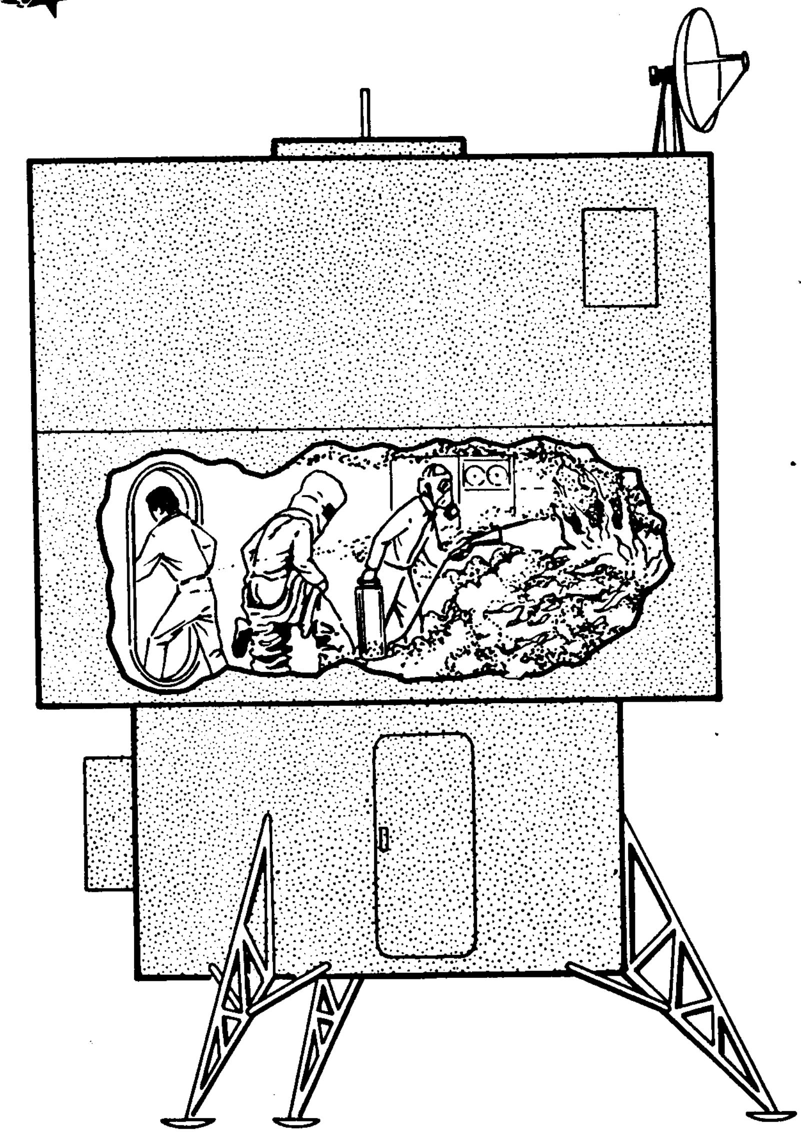
- TUG MAY BE AT ANY LOCATION ON LUNAR SURFACE
- CREWMEN MAY BE INCAPACITATED
- MEDICAL AID MAY BE NECESSARY
- CREW MAY BE IN SHIRTSLEEVES OR PRESSURE SUITS
- CABIN MAY BE PRESSURIZED OR EVACUATED

TYPICAL HAZARDS WITH LUNAR SURFACE BASES

Hazards with a Lunar Surface Base (LSB) are less serious, in general, than with a solo lunar lander tug since more crew members are available to assist one another, several pressure compartments are available, more consumables are carried, and tugs are expected to be standing by.

TYPICAL HAZARDS—LSB



- HAZARDOUS CONDITIONS:
  - LOSS OF ATMOSPHERE
  - INJURY/ILLNESS
  - INADEQUATE CONSUMABLES
  - ISOLATION ON THE SURFACE
- SUBSEQUENT TO:
  - FIRE
  - EXPLOSION
  - COLLISION
  - METEOROID PUNCTURE
  - CONTAMINATION
  - CARGO/EQUIPMENT HANDLING ACCIDENT

TYPICAL SAFETY GUIDELINES FOR LUNAR SURFACE BASES

- **Each lunar surface base shall have parked near the site space tug vehicles with crew compartments, propulsion modules, and instrument units capable of housing and supporting the entire base crew.**
- Each lunar surface base shall be provided with alternate access ports, alternate access/ escape routes, and alternate means for transporting incapacitated crewmen from surface to base and base to surface.
- The movement of large pieces of equipment or of modules on the lunar surface should be accomplished with the astronaut nearby and guiding and controlling such movement but not aboard the carrying vehicle. Thus in the event of module transport vehicle upset, tipover, etc., he will not be trapped or injured.
- Very severe requirements for noncombustibility of materials used in constructing the LSB should be observed.
- Enough tugs should always be available at a lunar surface base to evacuate the entire crew to lunar orbit should the LSB have to be abandoned.
- The following items are forbidden in or very close to the LSB:
  a. handling or storage of hypergolic chemicals.
  b. handling or storage of pyrotechnic devices.
  c. combustible fluids in the thermal control system.
- A nuclear power source used to generate electrical power shall be stationed at least 2000 feet from the LSB; preferably in a crater whose walls are higher than the reactor container and that have been thickened by moving soil.
- Secondary power sources should be available for the LSB in the event of nuclear source malfunction. Such secondary sources should be adequate to maintain all life support and essential communications functions until repairs are made or rescue or return to orbit effected.

TYPICAL CORRECTIVE MEASURES-LSB

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- MULTIPLE PRESSURIZED COMPARTMENTS
- EMERGENCY PRESSURE GARMENTS
- EMERGENCY OXYGEN MASKS
- PRESSURE SUIT FOR EACH CREWMAN
- TUGS AVAILABLE TO ACCOMMODATE CREW
- CABIN ROVER TO ACCOMMODATE CREW
- BACKUP AND EMERGENCY CONSUMABLES
- ALTERNATE ESCAPE ROUTES
- CONTAMINANT MONITORING AND CONTROL
- FIRST AID
- AIRLOCK TO ACCEPT STRETCHER CASE PLUS ONE EVA CREWMAN
- PREPARED LANDING PADS
- REMOTE HANDLING OF HEAVY EQUIPMENT
- SHIRTSLEEVE TRANSFER BETWEEN LSB AND CABIN ROVER

LUNAR SURFACE BASE/ROVER INTERFACE SAFETY EFFECTS

The chart is presented to illustrate interface features that have been examined in the effort to improve operational safety.

LSB ROVER INTERFACE SAFETY EFFECTS

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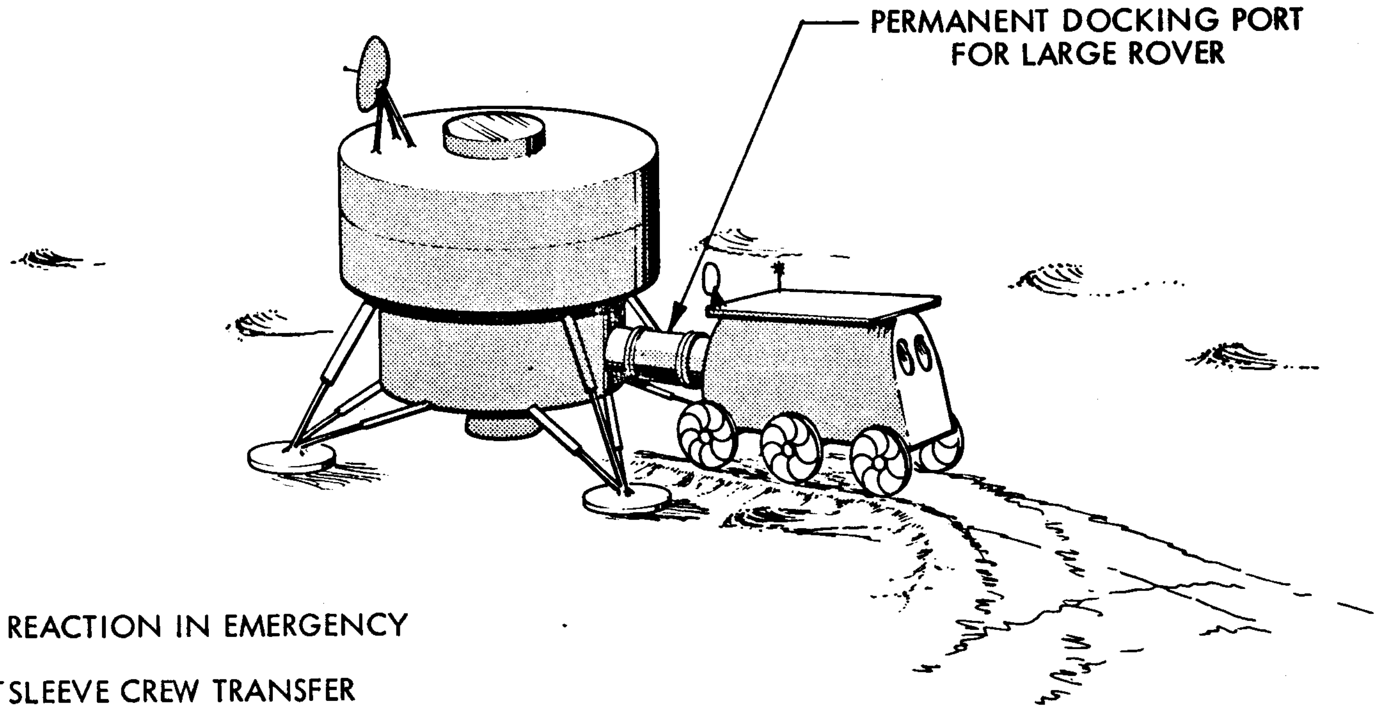

- FAST REACTION IN EMERGENCY
- SHIRTSLEEVE CREW TRANSFER
- AVOIDS AIRLOCK HAZARDS
- PROVIDES ALTERNATE EMERGENCY SHELTER

TYPICAL ESCAPE/RESCUE REQUIREMENTS FOR LUNAR SURFACE BASES

The escape/rescue requirements reflect the expanded activities at a large lunar surface base. In general, the need for outside assistance should be less likely since the crew size is increased, additional equipment is carried, longer durations are provided for, and return tugs are expected to remain with the base to provide a capability to return all crewmen to lunar orbit.

TYPICAL ESCAPE/RESCUE REQUIREMENTS-LSB

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- EARTH-SIDE LOCATION
- CREWMEN MAY BE INCAPACITATED
- MEDICAL AID MAY BE NECESSARY
- CREW MAY BE IN SHIRTSLEEVES OR PRESSURE SUITS
- CABIN MAY BE PRESSURIZED OR EVACUATED
- CREWMEN MAY BE IN BASE, TUG, CABIN ROVER, OR EVA

TYPICAL HAZARDS WITH EVA ROVERS

Operation with a non-cabin rover introduces hazards inherent with a small vehicle, with navigation and motion over the hostile lunar surface, and with operations while wearing a restrictive EVA pressure suit and carrying consumables in a backpack. Reaction times in an emergency may be much more critical than for a crew in shirtsleeves in a large pressure cabin.

TYPICAL HAZARDS-EVA ROVER

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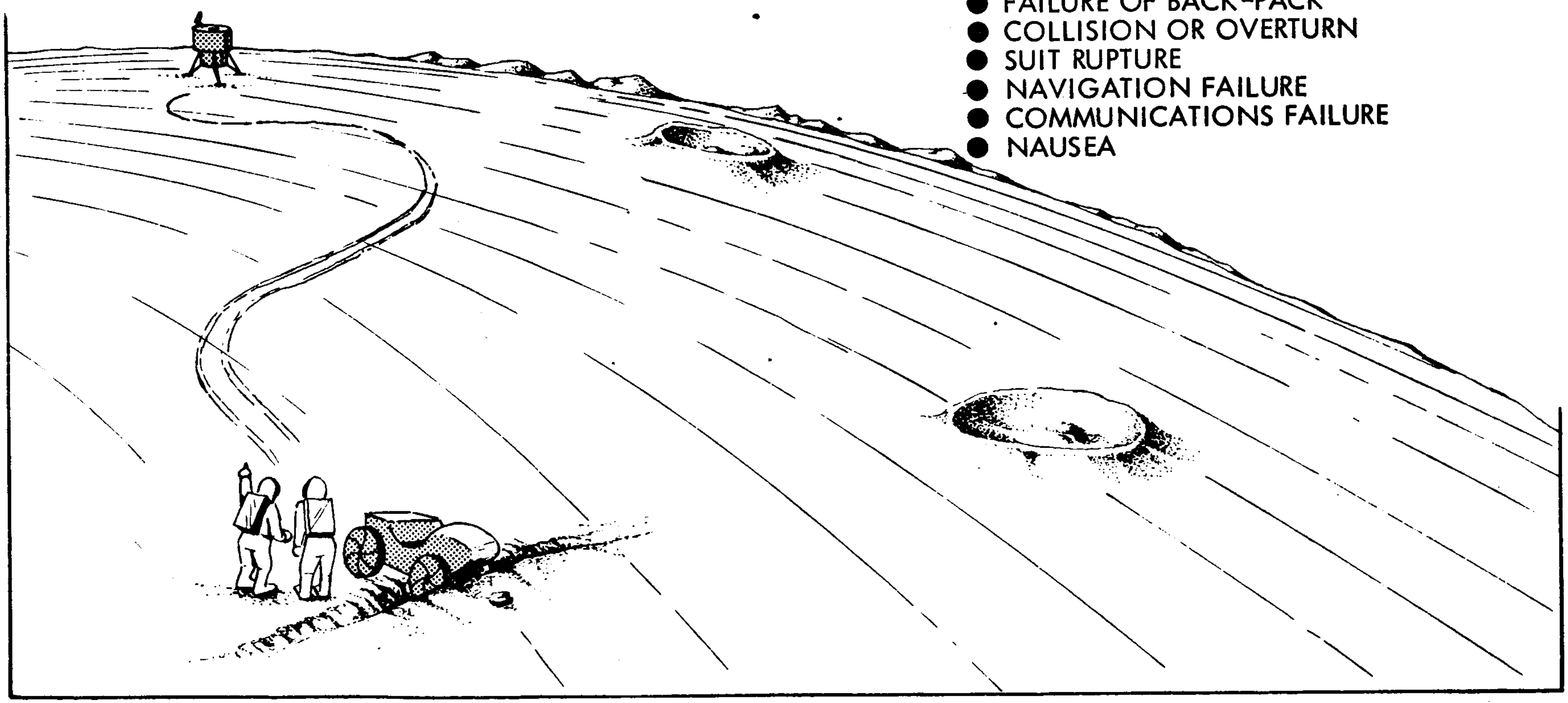


- HAZARDOUS CONDITIONS:
  - ISOLATION
  - INADEQUATE CONSUMABLES
  - INJURY/ILLNESS/VOMITING
  - NO LIFE SUPPORT
  - NO COMMUNICATIONS
- SUBSEQUENT TO:
  - ROVER FAILURE OR ENTRAPMENT
  - FAILURE OF BACK-PACK
  - COLLISION OR OVERTURN
  - SUIT RUPTURE
  - NAVIGATION FAILURE
  - COMMUNICATIONS FAILURE
  - NAUSEA

TYPICAL SAFETY GUIDELINES FOR EVA AND EVA ROVER

- Non-cabin lunar surface rovers shall not operate beyond walk-back distance to a safe haven, unless such rovers are operated in pairs with each capable of supporting the other and returning all crewmen to safe haven.
- Each roving vehicle shall be completely operable and drivable by a single crewman.
- Lunar surface roving vehicle design features should include lap belts and shoulder restraints, roll bars or similar protection from injury in the event of vehicle overturn, and surface slope warning indicators.
- Lunar surface rovers shall carry redundant communications equipment, radio beacons, and visual and auditory signalling devices to aid in rescue.
- The buddy system should be mandatory for EVA astronauts under normal conditions unless they are within a few tens of meters of the LSB or of the cabin rover or of the landed tug, and standby help is immediately available.
- Back-pack design shall permit buddy system (backpack-to-backpack) attachment and operation for all life support functions and power and communications.
- Back-pack switching in the lunar vacuum environment shall not be required as a means for normal extension of mission duration.
- All back-packs and inter-related equipment should be designed to fail-operational, fail-operational, fail-safe.
- Space suit design efforts should continue to stress increased astronaut mobility performance capabilities, integration of separate suit elements into one garment, increased resistance to tear and abrasion and emergency corrective measures to prevent catastrophic suit leaks.

TYPICAL CORRECTIVE MEASURES — EVA ROVING TRAVERSE

LOCKHEED

- NO EVA BEYOND WALK-BACK DISTANCE; LIMIT ALL EVA
- USE BUDDY SYSTEM
- BUDDY BACK-PACKS
- FAIL-OP., FAIL-OP., FAIL-SAFE SUIT/BACK-PACK DESIGN
- INTEGRATED SUIT/BACK-PACK DESIGN
- NO BACK-PACK SWITCHING NORMALLY REQUIRED
- EMERGENCY BACK-PACK SWITCHING AND SWITCHING AIDS
- IMMEDIATE RETURN TO BASE FOLLOWING FAILURE
- EMERGENCY CONSUMABLES
- SUIT RUPTURE REPAIR KIT
- HANDLING PROVISIONS FOR INJURED
- FIRST AID/FACE PLATE ACCESS
- EXTERNAL LIFE SUPPORT PLUG-INS ON ALL CABINS
- ROLL BAR AND CREW RESTRAINTS

TYPICAL ESCAPE/RESCUE REQUIREMENTS FOR EVA ROVER

Escape/rescue requirements for crewmen on EVA with a non-cabin rover may be quite demanding. With crewmen always in pressure suits, and consumables sharply limited, the rescue plan must provide fast reaction and a capability to give first aid to the man in the suit.

TYPICAL ESCAPE/RESCUE REQUIREMENTS—EVA ROVER

- FAST REACTION REQUIRED
- CREWMEN MAY BE INJURED/INCAPACITATED
- MEDICAL AID MAY BE NECESSARY
- MEN WILL BE IN PRESSURE SUITS
- LOCATION MAY NOT BE PRECISELY KNOWN

SAMPLE SAFETY GUIDELINES

Two hundred and twenty seven safety guidelines are proposed and recommended for implementation in the Final Report Technical Summary, MSC-03976. The three guidelines reproduced on the chart are typical examples.

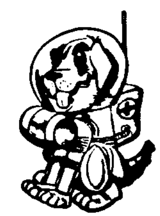
SAMPLE SAFETY GUIDELINES

- CREW MODULES, SERVING ESSENTIALLY AS REPLACEMENT-CREW DELIVERY SHELTERS, SHALL HAVE THE CAPABILITY (AS A MINIMUM) TO QUICKLY SEPARATE AND MOVE AWAY FROM A DISABLED (STABLE OR TUMBLING) PRIME TRANSPORT VEHICLE, PROVIDE A DELTA VELOCITY OF APPROXIMATELY 1000 FT/SEC TO ACHIEVE AN ELLIPTICAL LUNAR ORBIT, AND MAINTAIN COMMUNICATIONS (BEACON AND VOICE), LIFE SUPPORT AND COARSE ATTITUDE WHILE AWAITING RESCUE.

- EACH CREW CABIN SHALL HAVE MORE THAN ONE PRESSURIZED COMPARTMENT CAPABLE, AT LEAST IN AN EMERGENCY, OF SUPPORTING THE CREW. HATCHES TO INTERCONNECTING PASSAGEWAYS OR AIRLOCKS SHALL BE KEPT OPEN AT ALL TIMES, BUT QUICKLY SEALABLE IN AN EMERGENCY.

- THE BUDDY SYSTEM SHOULD BE MANDATORY FOR EVA ASTRONAUTS UNDER NORMAL CONDITIONS UNLESS THEY ARE WITHIN A FEW TENS OF METERS OF THE LSB OR OF THE CABIN ROVER OR OF THE LANDED TUG, AND STANDBY HELP IS IMMEDIATELY AVAILABLE.

ESCAPE/RESCUE
ANALYSIS
RESULTS



LUNAR ARRIVAL/DEPARTURE ESCAPE/RESCUE SITUATIONS

At Lunar Orbit Insertion (LOI) or TransEarth Injection (TEI) a nominal ΔV of 3000 ft/sec must be imparted to the Prime Transport Vehicle (PTV). This ΔV must be removed for LOI or added for TEI at a nominal 60 nm altitude. Failure of either propulsion (in terms of total impulse) or guidance (i.e., thrust vector control) during burn can result in one of a family of elliptic or hyperbolic trajectories.

The trajectories can be categorized as either impact or non-impact. The impact trajectories have reaction times of a few minutes (8 to 10) to several hours (high elliptic trajectory). The most critical is the immediate impact (hyperbolic on elliptic) followed by the elliptic whose perilune (below the lunar surface) will not be reached for an hour. The third impact trajectory is the high ellipse which must pass through apolune before returning to perilune below the lunar surface. The non-impact trajectories can be elliptical (a relatively safe condition) or hyperbolic (which is still time-critical but not of the same order of magnitude as the impact trajectories).

ESCAPE / RESCUE SITUATIONS

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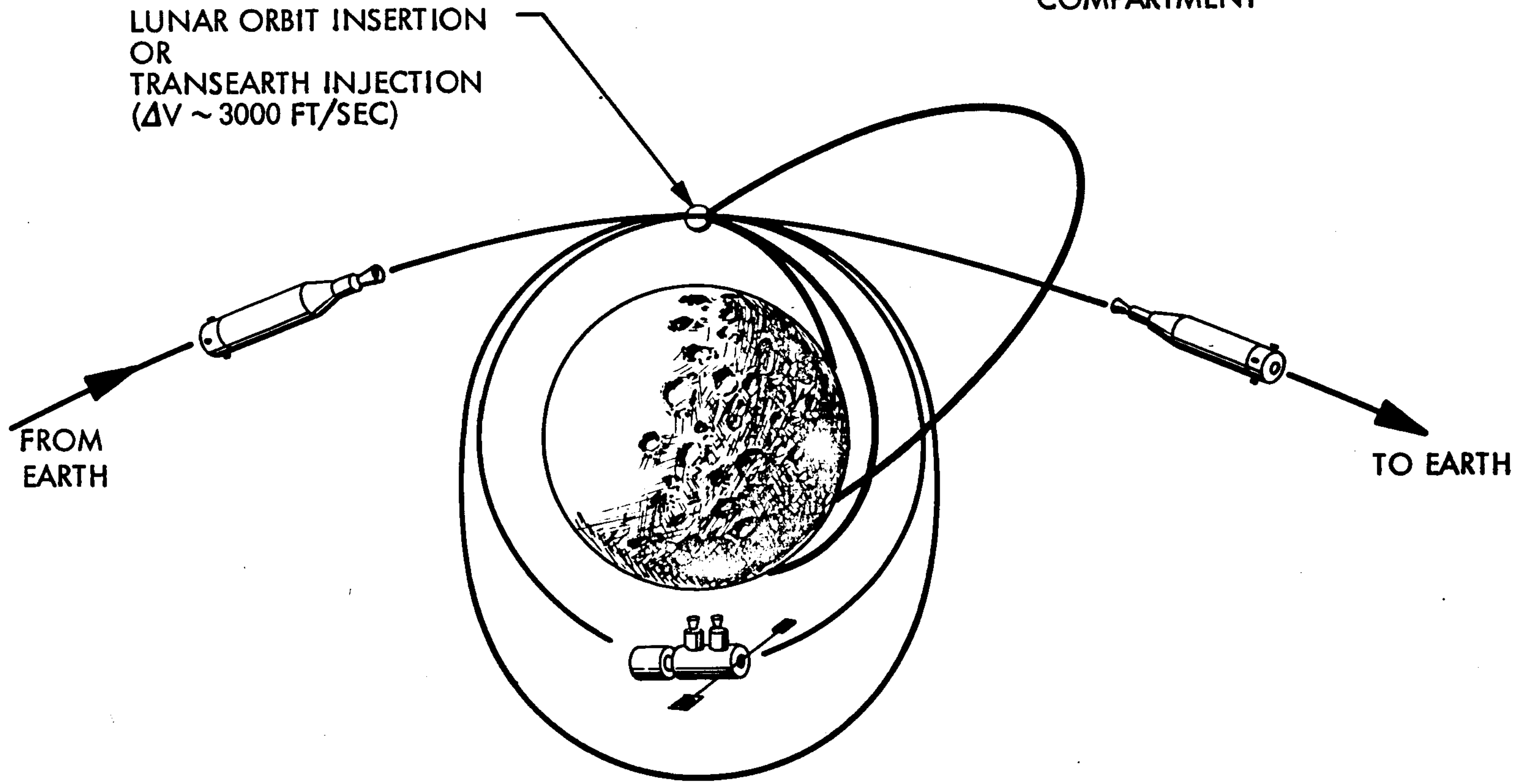
LUNAR ARRIVAL/DEPARTURE

- INITIAL MANNING FLIGHT
  PTV WITH TUGS
  (OLS IN LUNAR ORBIT)
- ROUTINE OPERATIONS
  PTV WITH CREW
  COMPARTMENT



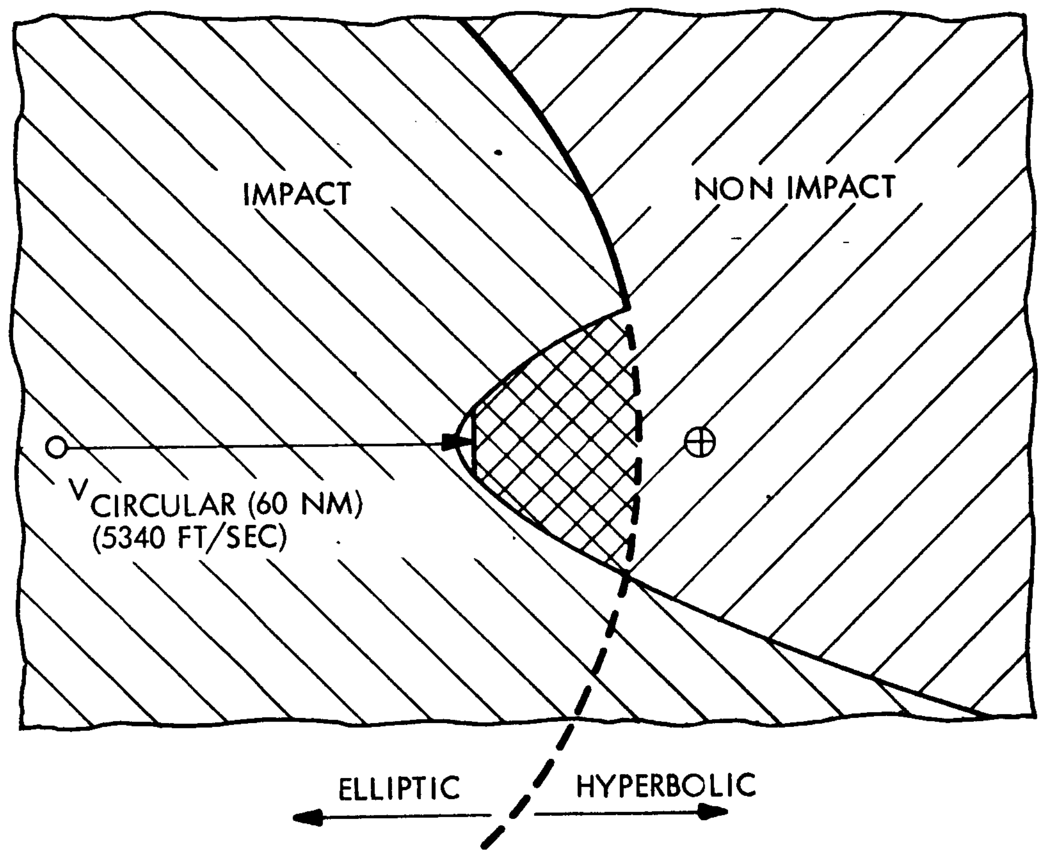
ARRIVAL/DEPARTURE VELOCITIES

The family of trajectories originating at the 60 nm perilune of the approach/depart hyperbola is defined by the velocities (magnitude and direction) at that point. The division between elliptic and hyperbolic is the parabolic escape velocity of 7550 fps at 60 nm altitude.

Parabolic velocity vector endpoints establish the constant radius curve in the chart. The desired circular velocity vector of 5340 fps is shown for reference. The solid curved line is the locus of endpoints for the velocity vectors of trajectories whose perilune is 50,000 ft and for the special hyperbolic trajectory case in which the manned vehicle has already passed through the perilune, and consequently will not impact. The region of non-impacting ellipses is the cup-shaped area between the solid and dotted lines.

It should be noted that the difference between the desired circular velocity and the ellipse with a 50,000 foot perilune is only 70 fps.

ARRIVAL / DEPARTURE VELOCITIES

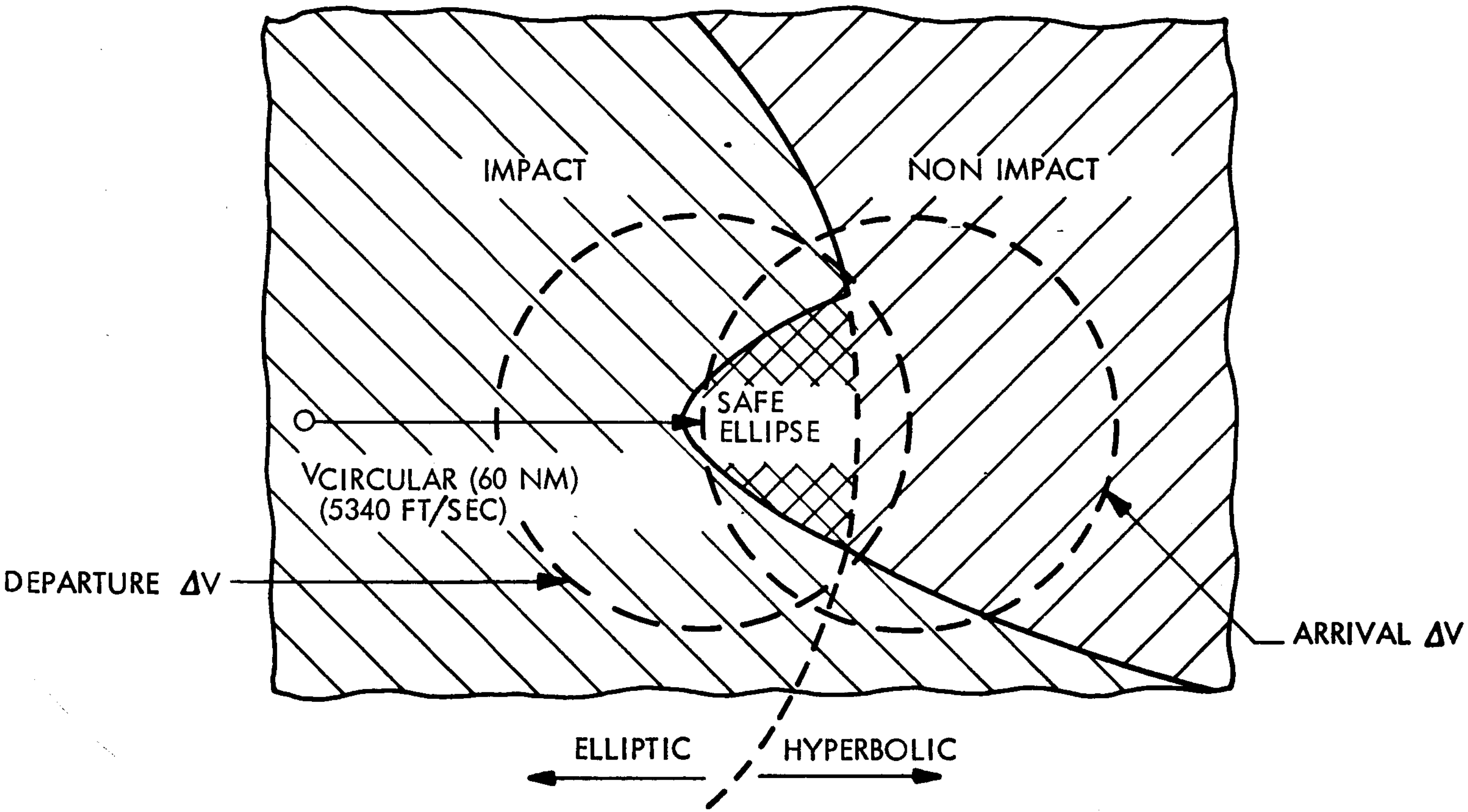


ARRIVAL/DEPARTURE VELOCITY ENVELOPES

The locus of possible velocity vector endpoints is shown by the dotted circles for the arrival and departure maneuvers, respectively. For a simple propulsion failure, where only the amount of impulse is in error but the thrust alignment is correct, the resultant velocity vector will lie along the horizontal coincident with the 60 nm circular velocity vector. For a guidance failure where the magnitude of the impulse is correct but in the wrong direction, the velocity vector endpoint will lie on the circle. For combined short burn and thrust direction misalignment or correct burn time, but varying thrust alignment cancelling some of the effective ΔV, the endpoint of the velocity vector will lie within the circle.

Assuming equal probability for all possible resultant velocity vectors, the hyperbolic escape/rescue situation is more likely for the arrival case while the departure case tends toward elliptical escape/rescue situations.

ARRIVAL / DEPARTURE VELOCITY ENVELOPES



ESCAPE/RESCUE ALTERNATIVES-ARRIVAL-INITIAL MANNING FLIGHT

The various arrival/departure alternatives shown are based on the data from the previous charts. For the impact situations, escape with the tug is essential. Once a relatively safe elliptic trajectory is attained, the tug can rendezvous with the unmanned OLS and continue on a curtailed mission. If the tug is unable to rendezvous with OLS, it can await Earth based rescue in the elliptic orbit. An alternative for the hyperbolic case is to return to Earth orbit for earth rescue.

ESCAPE / RESCUE ALTERNATIVES—ARRIVAL

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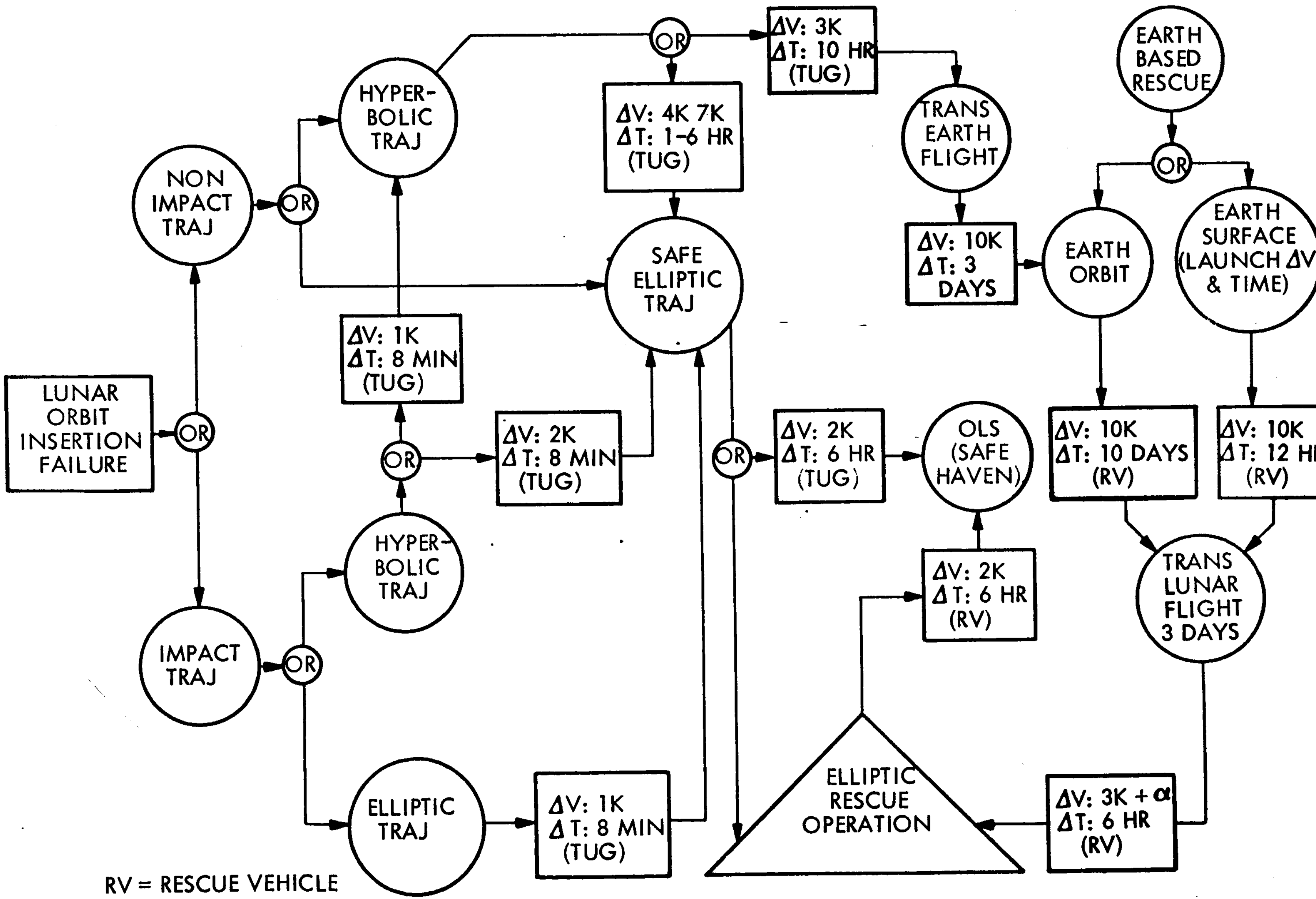
INITIAL MANNING FLIGHT



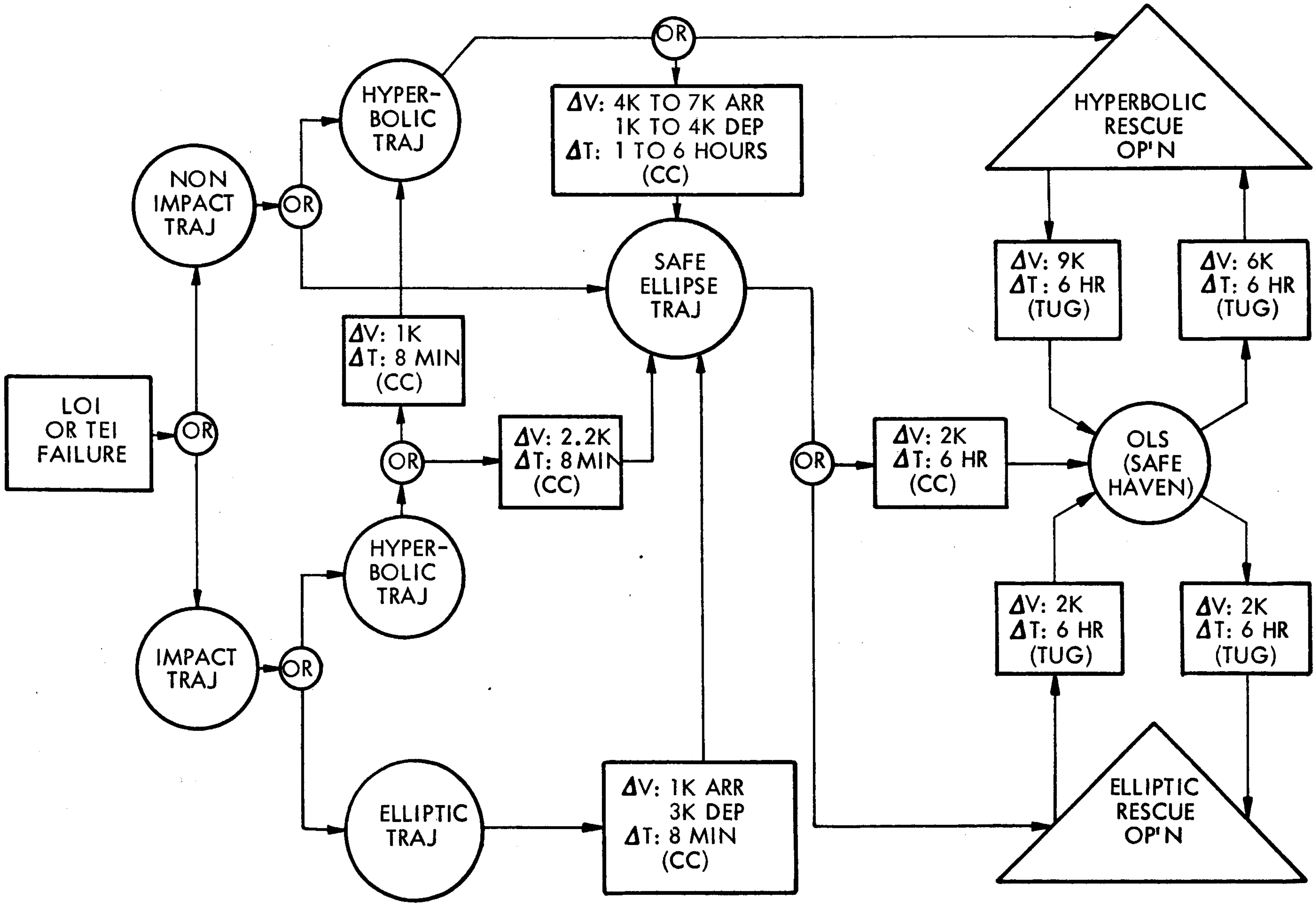
RV = RESCUE VEHICLE

ESCAPE/RESCUE ALTERNATIVES – ARRIVAL/DEPARTURE-ROUTINE OPERATION

The situations are essentially the same as for the previous "Initial Manning Flight" except that the crew is being transported in a crew compartment (CC) attached to the PTV. However the OLS is now manned and has a tug available to perform rescue operations from non-impact trajectories, either hyperbolic or elliptic. For additional ΔV capability the crew compartment could return to the OLS. The ΔV impulses and times are for a nominal 96-hour translunar flight time.

ESCAPE/RESCUE ALTERNATIVES ARRIVAL/DEPARTURE

ROUTINE OPERATION



CC = CREW COMPARTMENT

ARRIVAL/DEPARTURE ESCAPE/RESCUE PLAN

In order to implement the preceding escape/rescue approaches, certain additional capabilities must be added to the Tug, Prime Transport Vehicle, and Crew Compartment. The most extensive additions will be to the crew compartment, converting it to a small autonomous vehicle.

An additional capability will be required for a nuclear powered PTV to prevent radiation exposure. An auxiliary attitude control system on the PTV, actuated from the crew compartment (or Tug), will be required to stabilize the PTV long enough for crew to escape to a safe radiation distance.

ARRIVAL / DEPARTURE ESCAPE / RESCUE PLAN

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INITIAL MANNING FLIGHT	ROUTINE CREW ROTATION

• CREW TRANSPORTED IN TUG
  • FULLY FUELED AND PROVISIONED
  • CAPABLE OF IMMEDIATE AND AUTONOMOUS ESCAPE
  • ABILITY TO RENDEZVOUS WITH OLS
  • EARTH RETURN CAPABILITY
• ACTIVATED PRIOR TO LOI
• AUTONOMOUS TRAJECTORY MONITORING BY CREW DURING MANEUVERS
• BACKUP EARTH RESCUE CAPABILITY
• AUTONOMOUS PTV STABILIZATION CONTROLLED FROM TUG
	• SEPARABLE CREW COMPARTMENT
	  • PROPULSION UNIT
	  • AUTONOMOUS GUIDANCE AND NAVIGATION
	  • IMMEDIATE ESCAPE CAPABILITY
	  • PROVISIONED FOR 7 DAYS
	  • ABILITY TO RENDEZVOUS WITH OLS
	  • COMMUNICATIONS WITH OLS
	  • AUTONOMOUS TRAJECTORY MONITORING
	• CREW COMPARTMENT ACTIVATED DURING MANEUVERS
	• TUG AT OLS MANNED AND ACTIVATED DURING ARRIVAL/DEPARTURE MANEUVERS
	• AUTONOMOUS PTV STABILIZATION CONTROLLED FROM CREW COMPARTMENT

ORBITING LUNAR STATION (OLS)

- INITIAL MANNING
- ROUTINE OPERATIONS

OLS INITIAL ACTIVATION

The initial Orbiting Lunar Station (OLS) manning operation may be made by either a nuclear or chemical propulsion prime transport vehicle (PTV). The payload can consist of the initial crew and either one or two tugs. Any rescue operation during the initial activation phase will not have the benefit of personnel and equipment in the lunar vicinity.

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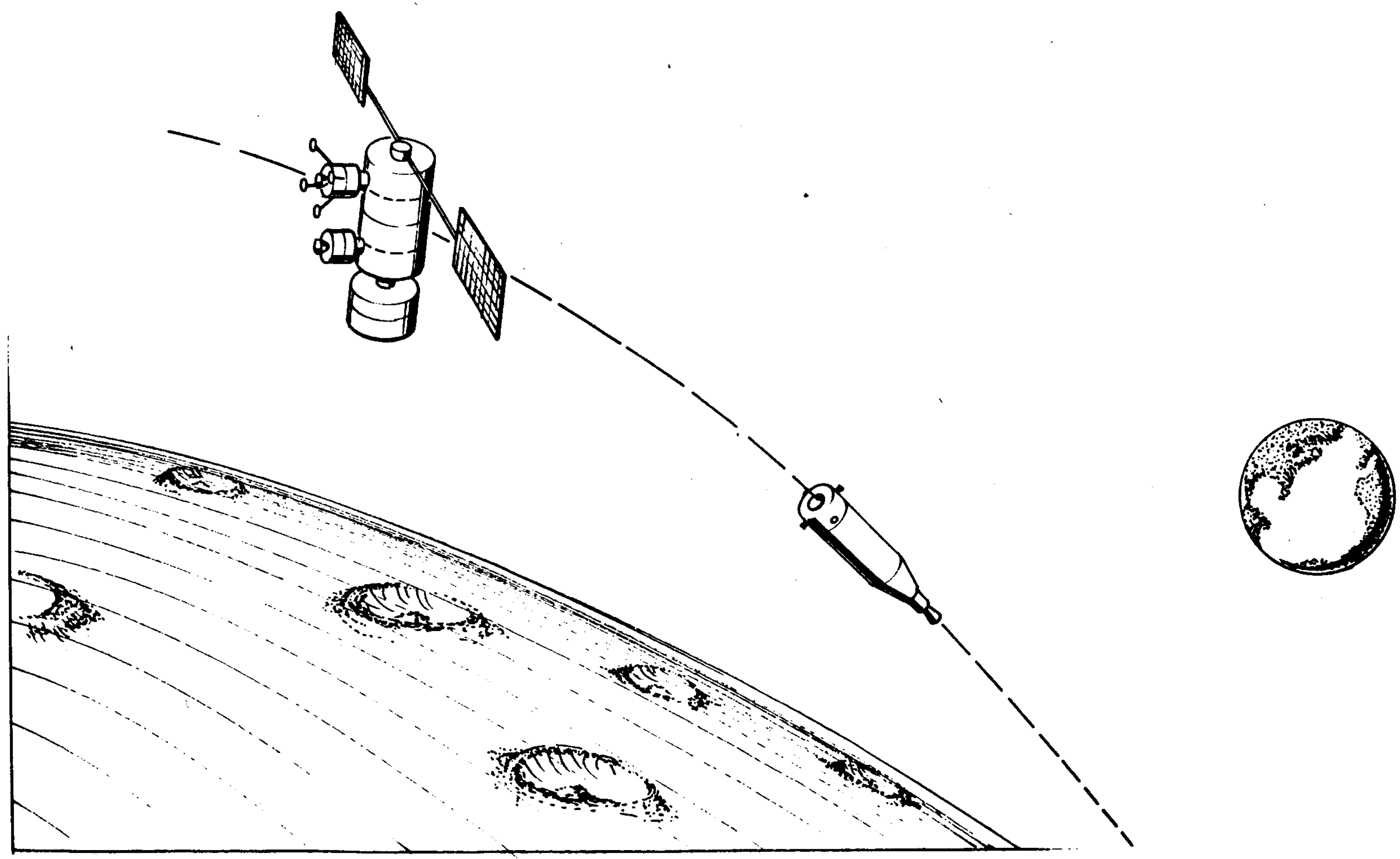
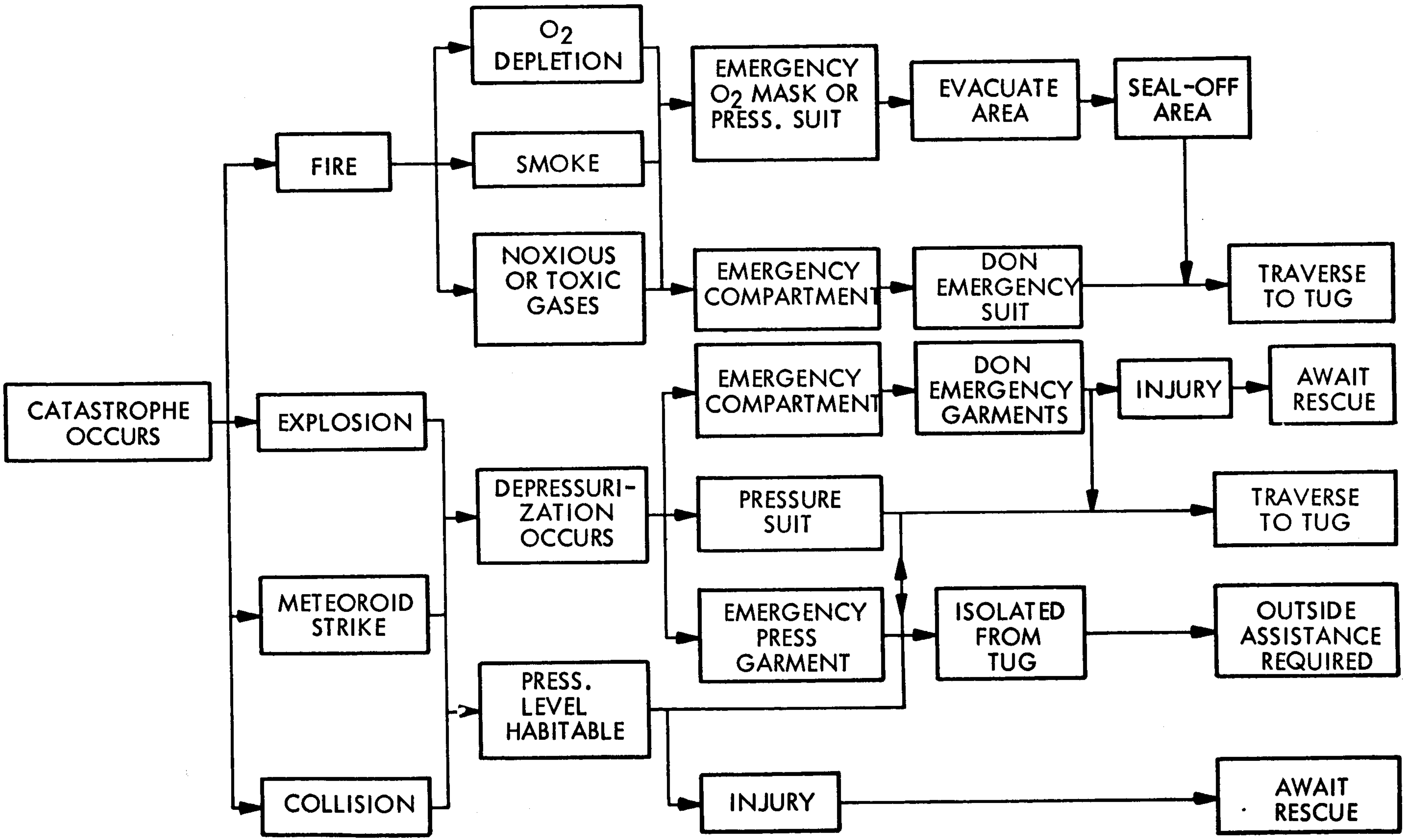
OLS INITIAL ACTIVATION



ESCAPE/RESCUE EVENT SEQUENCE

In a catastrophic failure situation the station sustains severe physical damage (such as a collision or meteoroid strike) and could be accompanied by fire or an explosion. Sudden and rapid depressurization may also occur as a result of structural damage by shrapnel, explosive force or a meteoroid. There are several event sequences that would be available to a crew following a station catastrophe. This chart depicts some of these possible sequences.

OLS ESCAPE/RESCUE EVENT SEQUENCE



OLS REQUIREMENTS/RESOURCES

The key requirements needed to accomplish the various available escape/rescue options and the corresponding required resources are presented on this chart. A rescue operation based in the Earth vicinity is needed for each option other than the first – using the tug for a direct return to Earth orbit.

OLS REQUIREMENTS/RESOURCES

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INITIAL MANNING

ESCAPE/RESCUE OPTION	REQUIREMENTS	RESOURCES
RETURN TO EARTH	ΔV 13,000 FT/SEC 5 DAYS LIFE SUPPORT	TUG DOCKED AT STATION
LEAVE STATION AND REMAIN IN LUNAR ORBIT	ΔV 100 FT/SEC 5 DAYS LIFE SUPPORT COMMUNICATIONS	TUG DOCKED AT STATION BACK-UP RESCUE CAPABILITY IN EARTH VICINITY
REMAIN IN STATION	5 DAYS LIFE SUPPORT COMMUNICATIONS	HABITABLE STATION BACK-UP RESCUE CAPABILITY IN EARTH VICINITY
REMAIN IN STATION IN EMERGENCY COMPARTMENT	5 DAYS LIFE SUPPORT COMMUNICATIONS	EMERGENCY COMPARTMENT IN STATION BACK-UP RESCUE CAPABILITY IN EARTH VICINITY

OLS ESCAPE/RESCUE PLAN OPTIONS

The choice of escape/rescue plan options depend on the usability of the docked tug. Usability is determined by crew condition and the effects of the station catastrophe on the docked tug. The plan requires a supporting Earth vicinity based rescue capability during the initial activation operation.

OLS ESCAPE/RESCUE PLAN OPTIONS

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INITIAL MANNING

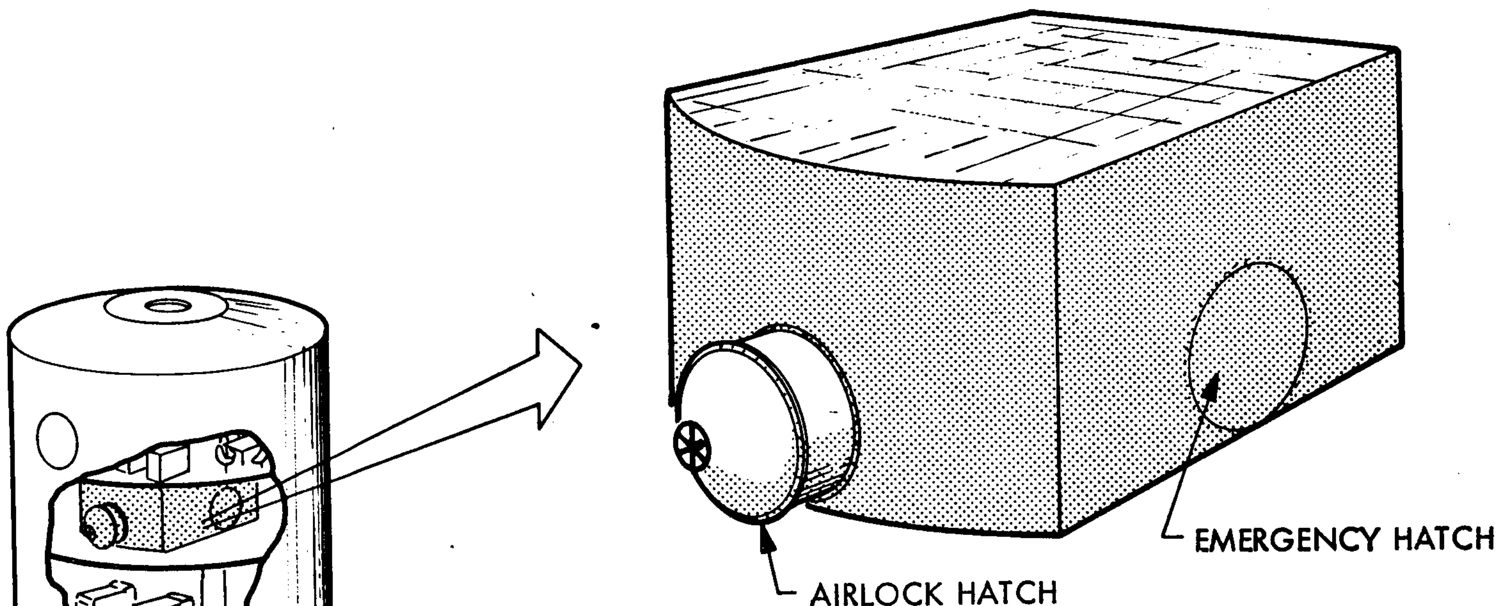
- TUG USABLE
  - RETURN TO EARTH
  - REMAIN IN LUNAR ORBIT
- TUG NOT USABLE
  - REMAIN IN STATION
  - USE EMERGENCY COMPARTMENT
- RESCUE FROM EARTH

OLS EMERGENCY EQUIPMENT

In a catastrophic OLS situation the rate of oxygen depletion, production of smoke or toxic gases, or depressurization, could be so rapid that a crewman would not have sufficient margins to traverse to a safe area. A possible alternative would be to enter an emergency compartment that would provide a temporary safe haven.

Such a compartment would need an airlock and emergency hatch compatible with a portable airlock. Additional required capability is tabulated on the accompanying chart.

OLS EMERGENCY EQUIPMENT



STATION

EMERGENCY COMPARTMENT

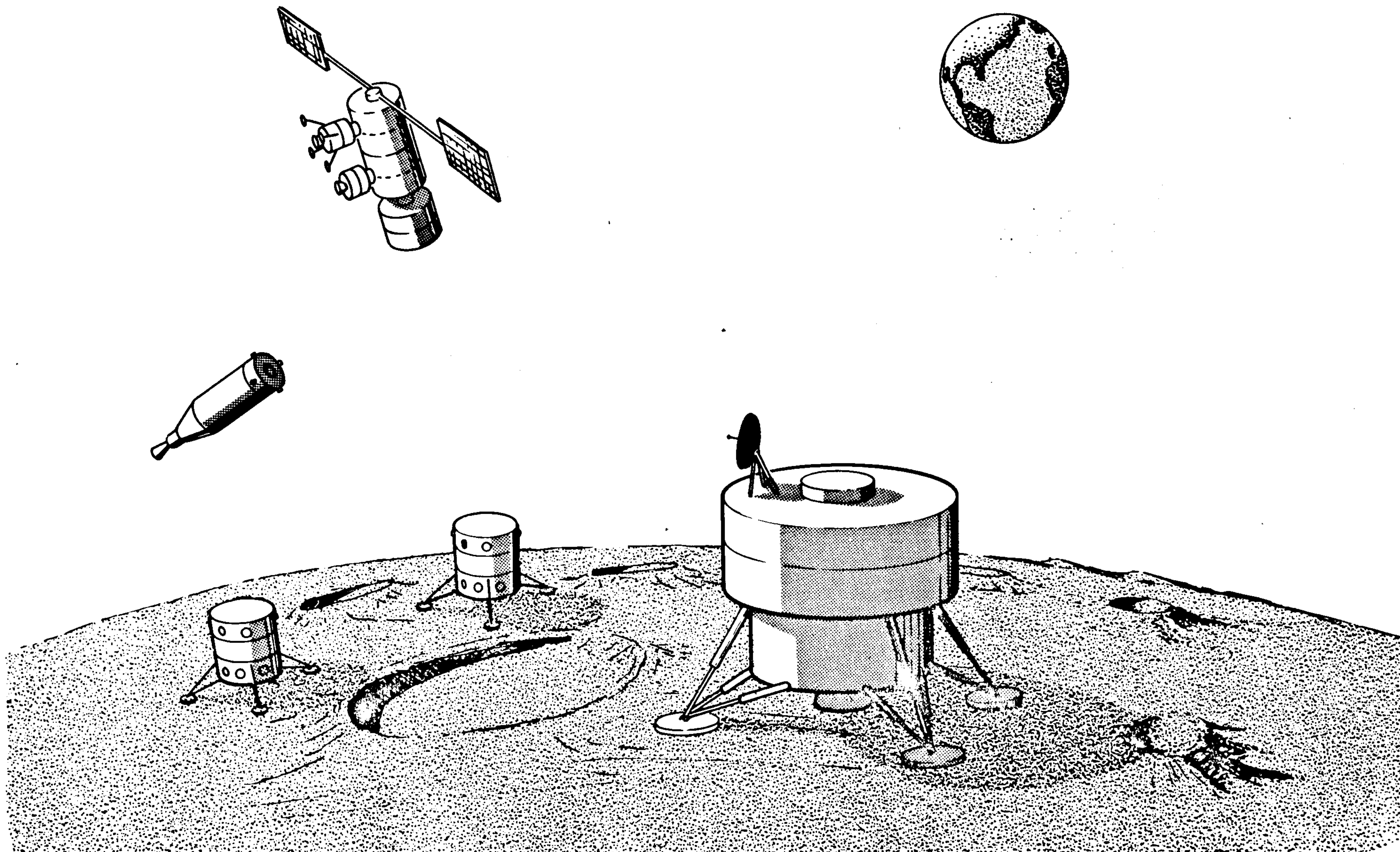
- LIFE SUPPORT
- FIRST AID
- EMERGENCY PRESSURE GARMENTS
- OXYGEN MASKS
- PRESSURIZED STRETCHER
- COMMUNICATIONS
- ECS
- POWER
- INSTRUMENTATION

OLS ROUTINE OPERATION SITUATION

The proposed key orbital hardware elements for use during the routine OLS operation phase are the OLS, space tug, prime transport vehicle and perhaps a fuel depot. Lunar lander tugs should start surface landings at various sites soon after the OLS reaches operational status. A perma-lunar surface base should also be established at a later date.

OLS ROUTINE OPERATION SITUATION

LOCKHEED



OLS ROUTINE OPERATIONS – REQUIREMENTS/RESOURCES

The escape/rescue options during the OLS routine operation phase are similar to those of the initial manning phase. The principal difference is the possible use of the LLT and LSB as potential escape/rescue bases. The key requirements needed to accomplish the various options and corresponding required resources are presented here.

Notice that a station rescue operation originating from any lunar surface site requires backup rescue support from the Earth vicinity.

OLS ROUTINE OPERATIONS

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REQUIREMENTS/RESOURCES

ESCAPE/RESCUE OPTION	REQUIREMENTS	RESOURCES
RETURN TO EARTH	ΔV 13,000 FT/SEC 5 DAY LIFE SUPPORT	TUG DOCKED AT STATION
ESCAPE TO LSB	ΔV 7300 FT/SEC TO 12,250 FT/SEC	TUG DOCKED AT STATION
ESCAPE TO LLT SORTIE SITE	ΔV 7300 FT/SEC TO 12,250 FT/SEC	TUG DOCKED AT STATION
RESCUE FROM EARTH VICINITY	5 DAYS LIFE SUPPORT COMMUNICATIONS	HABITABLE STATION TUG DOCKED AT STATION
RESCUE FROM LSB	ΔV 6690 TO 12,250 FT/SEC BACK-UP RESCUE FROM EARTH VICINITY	BACK-UP RESCUE CAPABILITY IN EARTH VICINITY
RESCUE FROM LLT SURFACE SITE	SAME	SAME

ESCAPE/RESCUE PLAN

Here are presented the recommended escape/rescue options for each of the two possible conditions of tug availability. The option of escape to the LSB should only be used if crew injuries require access to better medical facilities than would be available aboard an orbital tug.

OLS ESCAPE/RESCUE PLAN OPTIONS

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STATION ROUTINE OPERATIONS

- TUG USABLE
  - REMAIN IN ORBIT/BACKUP RESCUE FROM EARTH VICINITY
  - ESCAPE TO LSB
- TUG NOT USABLE
  - RESCUE FROM LSB OR LLT SORTIE SITE
  - BACKUP RESCUE FROM EARTH

SURFACE OPERATIONS

- LLT SORTIE
- LUNAR SURFACE BASE
- TRAVERSE

LLT SORTIE SITUATION

Lunar Lander Tug (LLT) surface sortie flights will probably be planned for descent and ascent in the orbit plane of the OLS. Landing sites on the Earthside of the Moon will always have potential communications capability with the Earth.

A typical LLT surface sortie mission would include a landing by the LLT, the use of surface mobility vehicles to deploy scientific experiments and to explore the lurain, and a staytime of up to 28 days.

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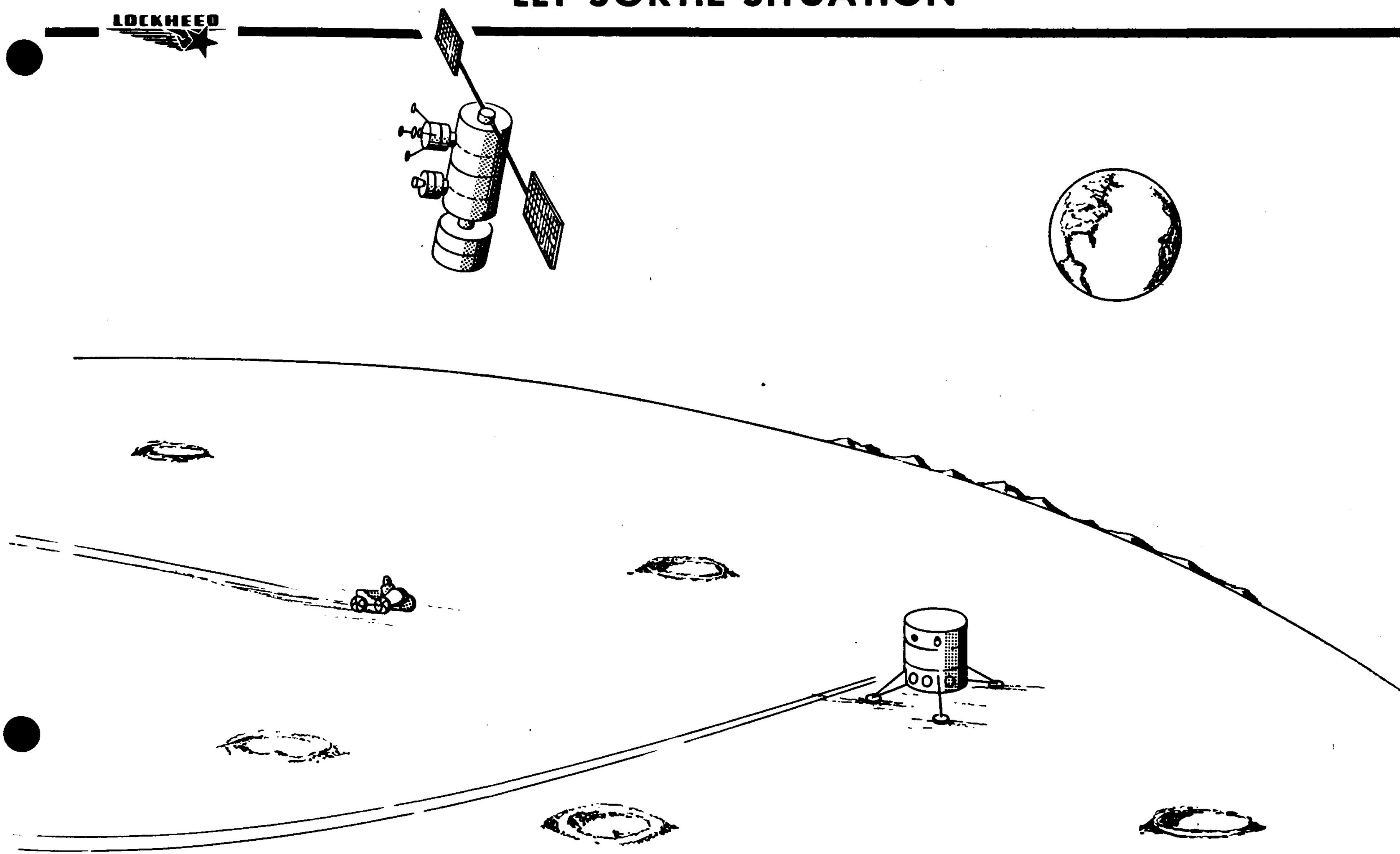
LLT SORTIE SITUATION



LLT MISSION FACTORS

Some of the sortie mission factors applicable to escape/rescue situations are shown here. Notice that the normal survival resources decrease to zero at the completion of the mission, leaving the planned allowances for ascent and return to the station plus an emergency capability allowance.

LLT MISSION FACTORS

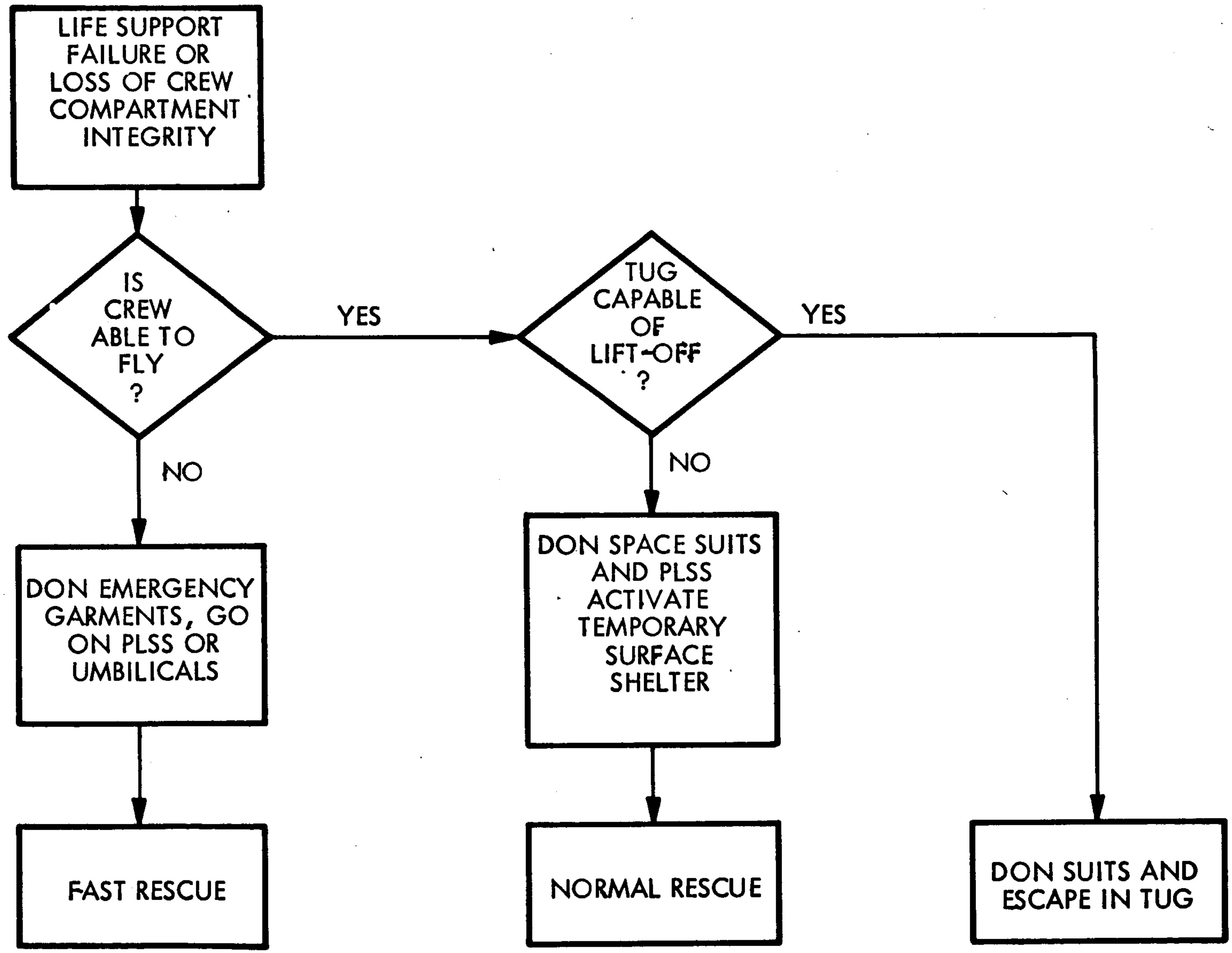
	LANDING AND DEPLOYMENT	ROUTINE OPERATIONS	DEACTIVATION AND DEPARTURE
• LANDING SITE LOCATION	NOT PRECISELY ESTABLISHED	COORDINATES ESTABLISHED	COORDINATES ESTABLISHED
• LIGHTING CONDITIONS	DAY	DAY OR NIGHT	DAY
• LANDING AIDS	NOT DEPLOYED	DEPLOYED	DEPLOYED
• LANDING SITE/STATION ORBIT PLANE CHANGE	0-15°	15°-90°	0-15°
• NORMAL SURVIVAL RESOURCES	28 DAYS*	28-0 DAYS*	0 DAYS*
• PERSONNEL ENVIRONMENT	SUITED	SUITED OR SHIRTSLEEVES	SUITED
• PERSONNEL LOCATION	IN TUG OR ON EVA CLOSE BY	IN TUG, EVA CLOSEBY OR ON SHORT RANGE TRAVERSE	IN TUG OR ON EVA CLOSE BY

*DOES NOT INCLUDE EMERGENCY CAPABILITY

LLT ESCAPE/RESCUE EVENT SEQUENCE

This chart presents a possible event schedule for a typical LLT escape/rescue situation.

LLT ESCAPE/RESCUE EVENT SEQUENCE



LLT SORTIE ESCAPE/RESCUE PLAN

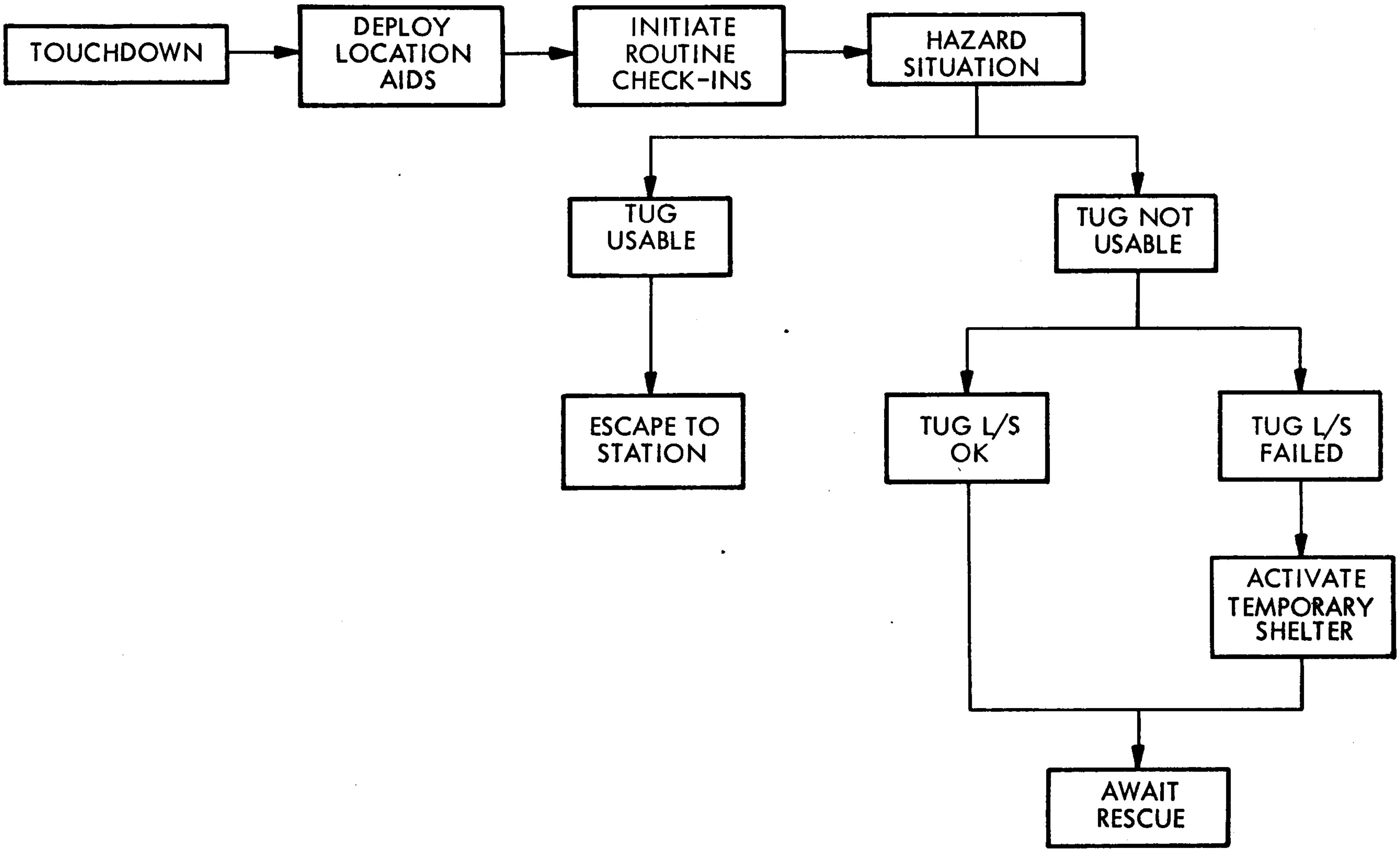
One of the priority tasks for the crew after touchdown on a sortie mission is the deployment of location aids. These aids include a beacon for navigating to the site and visual boundary markers for both light and night conditions.

Routine communication checks with both the Earth vicinity and OLS would be initiated immediately. Non-receipt of these periodic communications would cause an automatic rescue alert.

A temporary shelter is needed to extend the crew survival time a minimum of 48 hours in the event of total failure of the LLT life support and ECS system.

LLT SORTIE ESCAPE/RESCUE PLAN

LOCKHEED

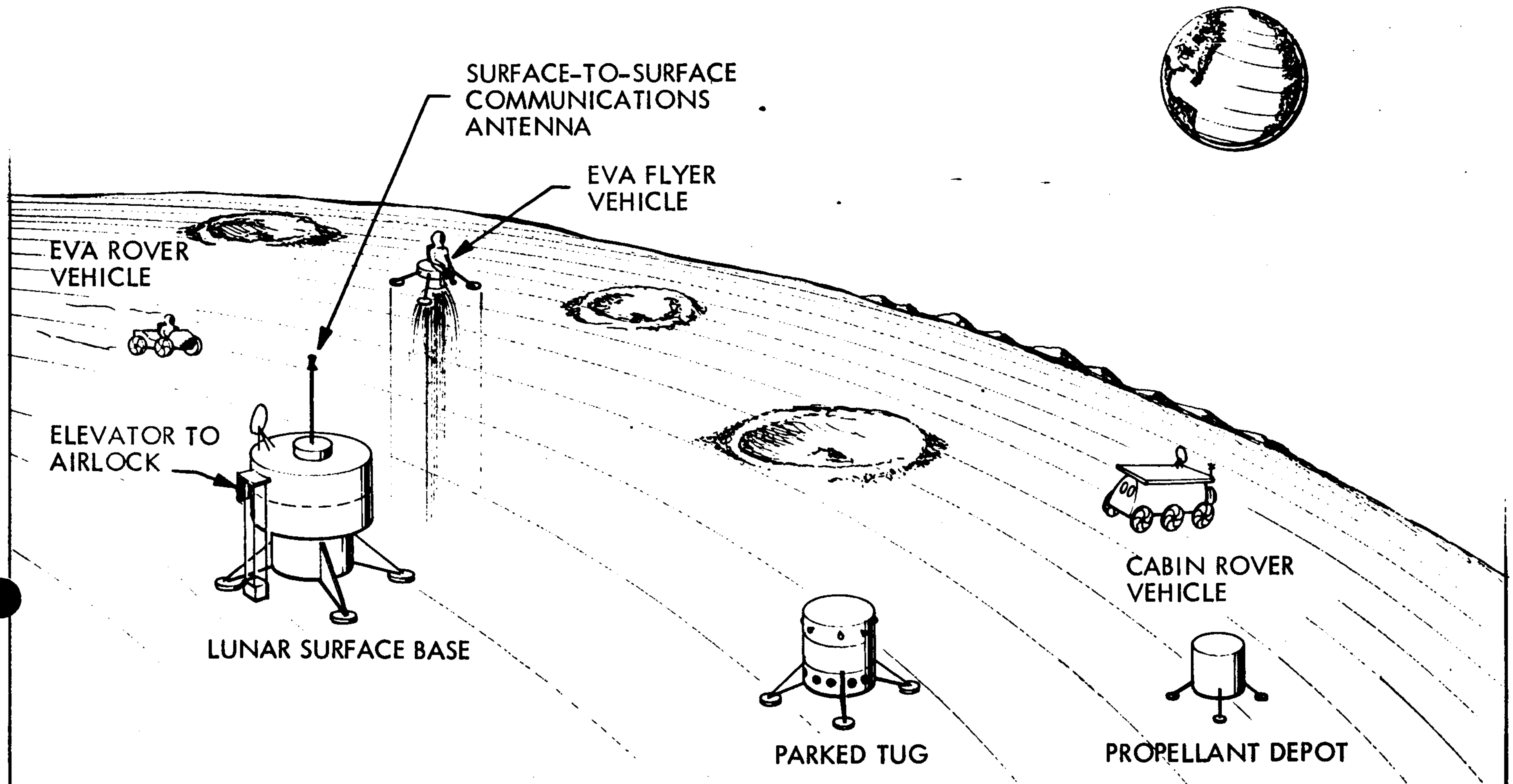


LUNAR SURFACE BASE OPERATION

Lunar Surface Base (LSB) operation will be similar to that of the LLT missions except that:

1. The LSB will be permanently located and in continuous operation over a period of several years
2. At least one LLT will be parked about 1.25 nm from the LSB at all times
3. Long traverses of several hundred nm for timespans as long as 28 days will probably be made.

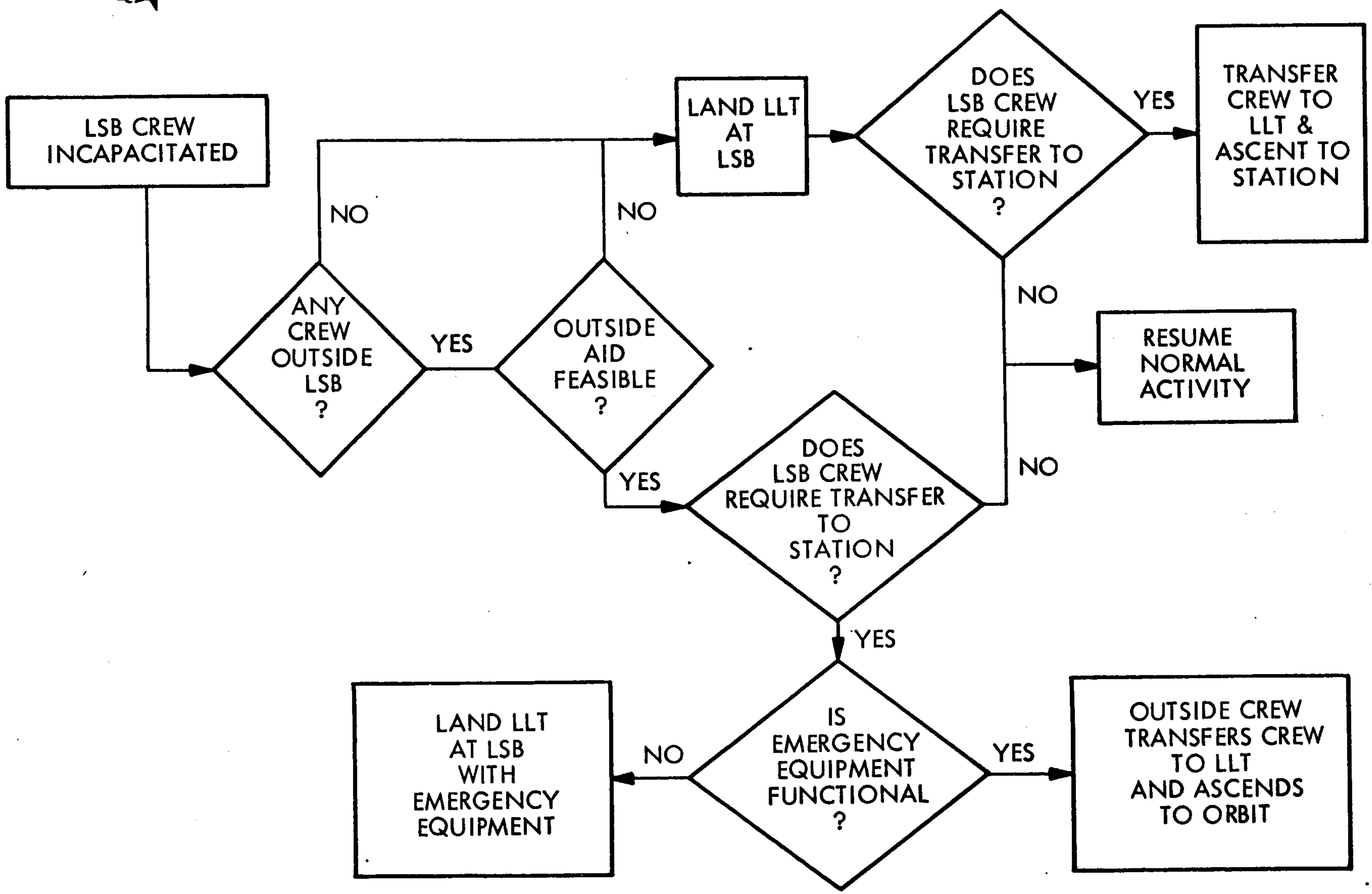
LUNAR SURFACE BASE OPERATION



LSB ESCAPE/RESCUE ALTERNATIVES

LSB escape/rescue alternatives revolve around two options: (1) escape using the parked LLT, and (2) rescue from orbit using a LLT docked to the OLS.

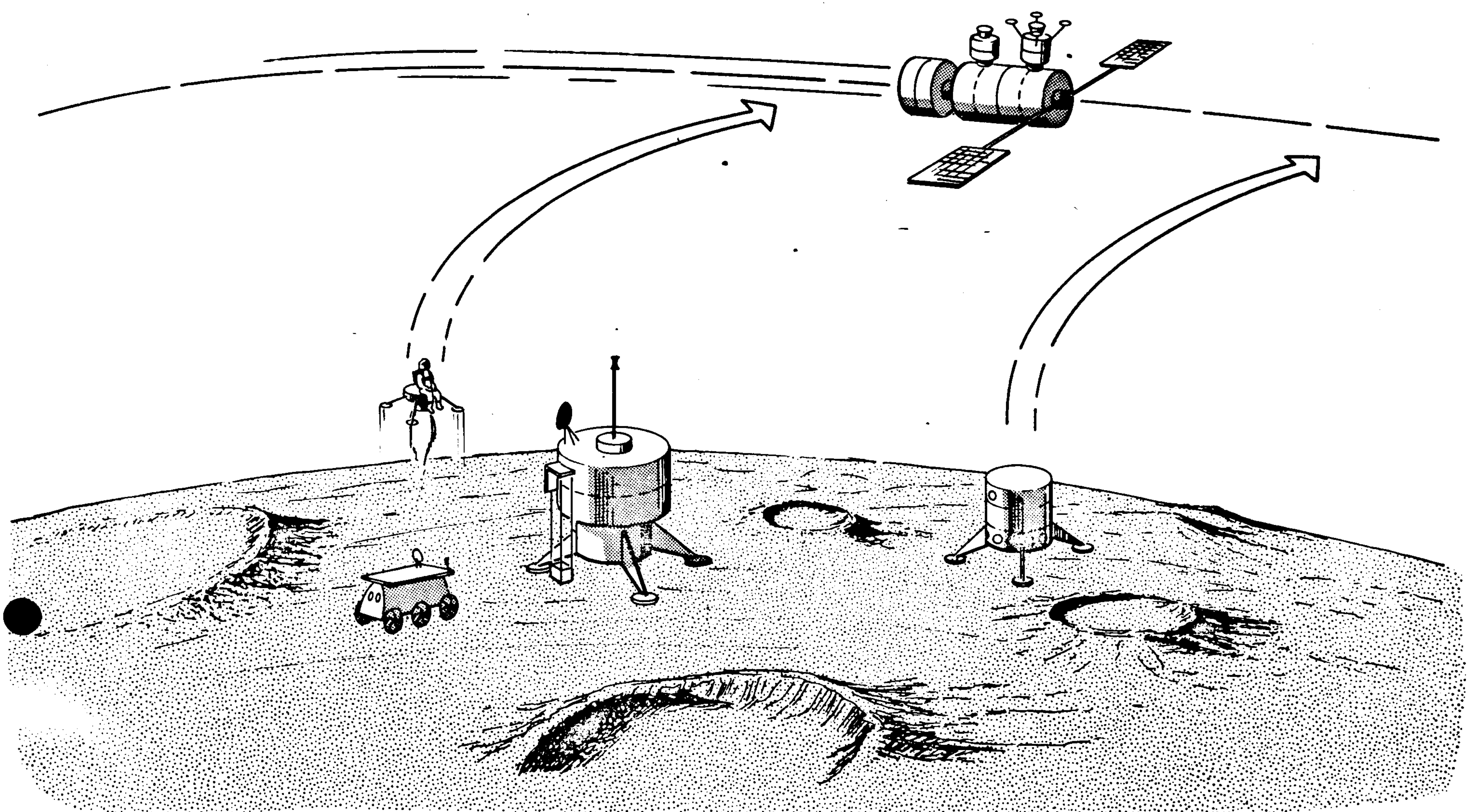
LSB ESCAPE/RESCUE ALTERNATIVES



LSB ESCAPE/RESCUE CONCEPTS

Applicable possible concepts are depicted on this chart. Some crewmen will probably always be in the LSB. If the LSB sustains a catastrophic failure, these crewmen could escape to the LLT, call in any crewmen on traverse in the near vicinity of the LSB and ascend to the station. If all the crew was trapped inside the station, an orbital rescue operation using an OLS based LLT would be necessary.

LSB ESCAPE/RESCUE CONCEPTS



LSB REQUIREMENTS/RESOURCES

This chart presents the key escape/rescue requirements and resources for the LSB. The available survival time and the response time for each escape/rescue option is also presented. Notice that the required response times exceed the normally available survival time spans .

LSB REQUIREMENTS/RESOURCES

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ESCAPE/RESCUE OPTION	SURVIVAL TIME	REQUIREMENTS	RESOURCES	RESPONSE TIME
ESCAPE TO STATION IN LESS TYPE VEHICLE	PLSS RESIDUAL	• AUTONOMOUS OP'N • MOBILE CREWMAN • ΔV = 6690 FPS • ORBITAL PICKUP	• LESS VEHICLES • ORBITAL TUG • UNUSED PLSS	8.75 HOURS (5.25 HRS ON PLSS)
ESCAPE TO PARKED LLT	SAME	• TRAVERSE CAPABILITY • ΔV = 6690 FPS • ORBITAL PICKUP	• LLT • ROVER VEHICLE	13.20 (3.75 HRS ON PLSS)
RESCUE FROM ORBIT	SAME	ΔV = 7300 FPS TO 15,050 FPS	ORBITAL TUG	10.75 HOURS
RESCUE FROM SURFACE LLT	SAME	3-MAN ROVER VEHICLE	o ROVER VEHICLE o LLT	10.70 HOURS

ORBITAL BASED RESCUE ΔV

There are two general approaches to establishing either an ascent or descent trajectory between the OLS and a particular site on the lunar surface such as the LSB. In an escape/rescue environment, a plane change of up to 90 degrees may be required during both the descent and ascent maneuver.

There are two ways of making this plane change: (1) make the plane change at orbital altitude, and (2) make the plane change at the apolune of a 30 hour period ellipse.

This chart presents the Δvelocity requirements for descent and ascent including the worst case condition of a 90 degree plane change during both maneuvers.

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ORBITAL BASED RESCUE ΔV

EVENT	PLANE CHANGE AT ORBITAL ALTITUDE		PLANE CHANGE AT ELLIPTICAL ORBIT APOLUNE (30 HR PERIOD)	
	ΔVELOCITY FT/SEC	CUM. ΔVELOCITY FT/SEC	ΔVELOCITY FT/SEC	CUM. ΔVELOCITY FT/SEC
● 90° PLANE CHANGE	7,750	7,750	4,800	4,800
● DESCENT AND LANDING	7,300	15,050	7,300	12,100
● ASCENT AND ORBIT INSERTION	6,690	21,740	6,690	18,790
● 90° PLANE CHANGE	7,750	29,490	4,800	23,590
TOTAL	29,490		23,590	

LSB ESCAPE/RESCUE PLAN RESOURCES

The LSB escape/rescue plan resources are presented here. Continuous communication with the Earth is required and with the station whenever it is orbiting on the Earthside. Suits and newly charged PLSS units are needed to furnish the maximum possible survival time for both the disabled and surface rescue crews. A fully fueled orbital based tug is needed to complete both the descent and ascent maneuvers.

A 3-man capacity rover (including the driver) is needed at the LSB to transport incapacitated crewmen to the parked LLT. A minimum of 48 hours of survival time is needed to permit a orbital based rescue tug to make a 90 degree plane change utilizing a 30 hr period elliptical orbit.

LSB ESCAPE/RESCUE PLAN RESOURCES

- CONTINUOUS COMMUNICATION CAPABILITY
- MAXIMUM CAPABILITY SUITS/PLSS
- FULLY FUELED ORBITAL TUG
- 3-MAN ROVER AT LSB AND ON ORBITAL TUG
- 48 HR SURVIVAL CAPABILITY
  EMERGENCY COMPARTMENT

TRAVERSE OPERATIONS

The various planned methods and vehicles for traverse operations and corresponding key escape/rescue characteristics are presented here. Note that survival time is constrained by the PLSS residual for EVA mode traverses. Cabin rover survival is also constrained by the PLSS residual if the emergency negates the pressurized cabin integrity.

TRAVERSE OPERATIONS

TRAVERSE MODE	SURVIVAL TIME	TYPICAL RANGE NM	TYPICAL VELOCITY KNOTS
WALKING	PLSS RESIDUAL	4	2.2
EVA ROVER	PLSS RESIDUAL	16	4
FLYER	PLSS RESIDUAL	10-30	180
GROUND EFFECTS MACHINE	PLSS RESIDUAL	20	14-20
CABIN ROVER	L/S OR PLSS RESIDUAL	200-?	5-6

TRAVERSE ESCAPE/RESCUE ALTERNATIVES

The minimum response times for various escape/rescue alternatives are presented in this chart. The critical survival time for EVA mode traverses reflects the possibility of the emergency occurring at the end of the mission with a 2-hour PLSS residual. The cabin rover critical survival time is based on a failure of the pressurized cabin and consequent crew dependency on their PLSS unit for survival.

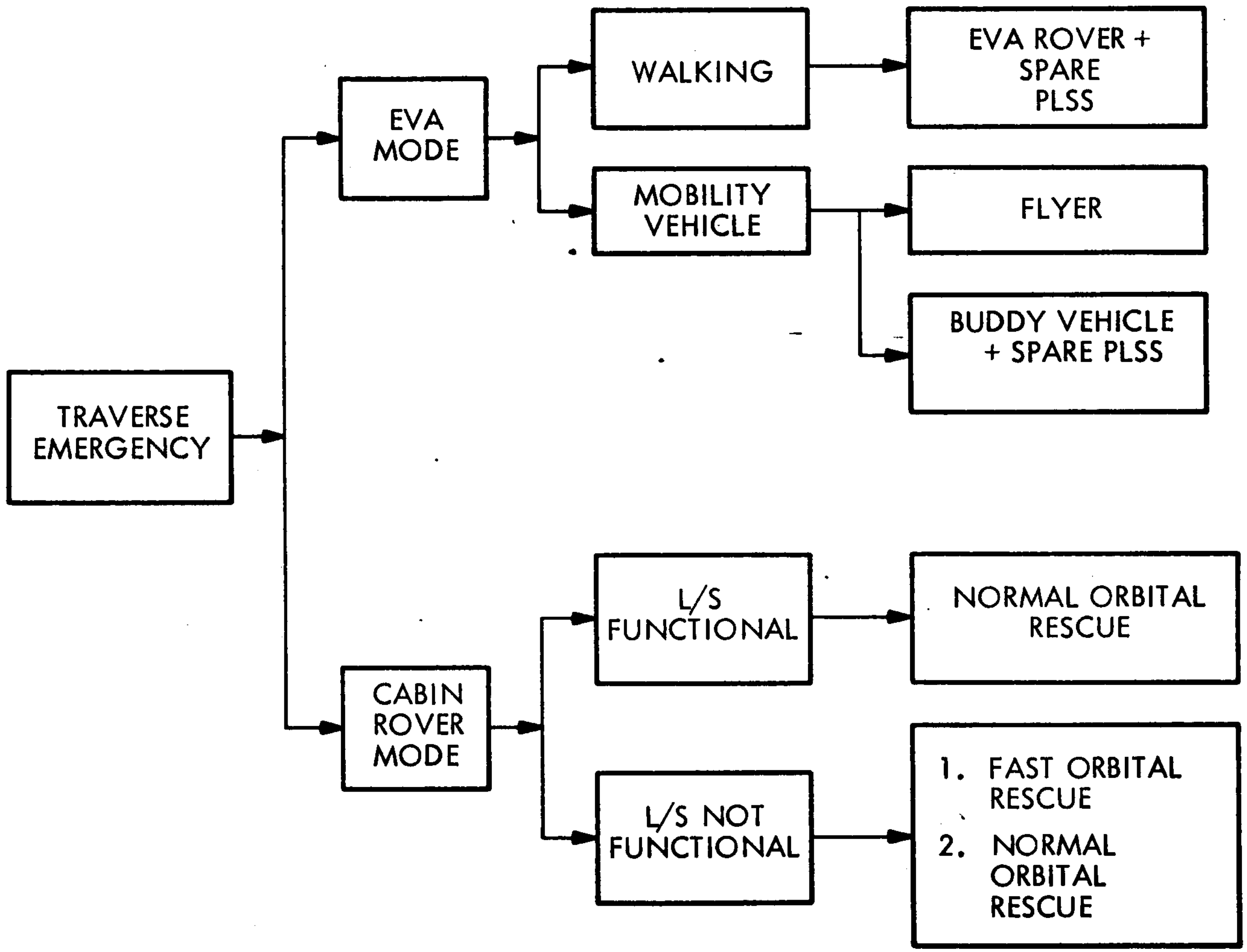
The escape/rescue approach that best meets the critical survival time need is indicated for each traverse mode.

TRAVERSE ESCAPE/RESCUE PLAN

The traverse escape/rescue plan is divided into two parts based on the use of either EVA or cabin rover mode vehicles. A spare PLSS unit is needed for the EVA mode with switchover by the crewman to the spare PLSS unit early enough in the EVA mission to permit a safe return to the LSB if the switchover is unsuccessful.

In the cabin rover mode,orbital based rescue capability is required due to the longer traverse ranges of the cabin rover vehicle.

TRAVERSE ESCAPE/RESCUE PLAN



TRAVERSE SURVIVAL APPROACHES

The key to a successful escape/rescue operation for traverse situations is crew survival. This chart presents promising approaches to extending crew survival in emergency situations.

TRAVERSE SURVIVAL APPROACHES

TRAVERSE MODE	BACK-UP PLSS	OPS	EMERGENCY PRESS GARMENT	EMERGENCY SHELTER	O_2 MASKS	THERMAL GARMENT
WALKING		X	X			
EVA ROVER	X	X	X			
FLYER	X	X	X			
GROUND EFFECTS MACHINE	X	X	X			
CABIN ROVER	X	X	X	X	X	X

ESCAPE/RESCUE SUMMARY

Feasible approaches to accomplish successful escape/rescue operations have been found for all emergencies that result in crew survival. Various equipment items and special procedures have been devised to increase the probability of survival.

All crews that perform missions requiring orbital maneuvers need sufficient ΔV capability to permit separation from the transport vehicle (tug or PTV) and injection into a non-impact lunar orbit.

An alert-status Earth vicinity based rescue capability is needed during OLS initial activation. A backup Earth vicinity rescue capability is needed in support of the OLS.

Minimum escape/rescue capability requires a tug Δvelocity capability of at least 15,000 feet/sec.

ESCAPE/RESCUE SUMMARY

- ESCAPE/RESCUE FEASIBLE
- SURVIVAL
  - LIFE SUPPORT
  - ENVIRONMENTAL CONTROL
- ORBITAL CREWS NEED ΔV CAPABILITY
- PRIMARY & SECONDARY EARTH-BASED RESCUE NEEDED
- TUG MIN. $\Delta V \sim$ 15,000 FT/SEC

SUMMARY

SAFETY REQUIREMENTS AND RECOMMENDATIONS

One of the more important products of the study is a number of safety requirements and recommendations which should be implemented in the quest for an acceptable level of safety in advanced lunar exploration. This chart presents those requirements and recommendations believed to merit the highest priority.

SAFETY REQUIREMENTS AND RECOMMENDATIONS

LOCKHEED

- RESTRICT THE USE OF EVA
- USE THE BUDDY SYSTEM FOR EVA, ROVERS, AND FLYERS
- PROVIDE A CAPABILITY TO SHARE BACK-PACKS
- USE HIGHLY TRAINED CREWMEN
- MAKE ALL VEHICLES OPERABLE BY ONE MAN IN SPACE SUIT
- PROVIDE MORE THAN ONE PRESSURE COMPARTMENT PER VEHICLE
- DESIGN FAIL-OP., FAIL-OP., FAIL-SAFE FOR ACS, POWER, & PROPULSION OF PTV, LLT, & FLYER; ALL FUNCTIONS FOR BACK-PACKS; POWER AND LSS FOR ROVERS

SAFETY REQUIREMENTS AND RECOMMENDATIONS (Cont)

LOCKHEED

- AN ORBITING LUNAR STATION IS NECESSARY TO SAFETY
- IPP HARDWARE ELEMENTS ARE SUITABLE FOR RESCUE
- PROVIDE RESCUE TUGS WITH MINIMUM ΔV OF 15,000 FT/SEC
- PROVIDE THREE TUGS IN THE LUNAR COMPLEX, TWO IN ORBIT
- PROVIDE A LUNAR BACKSIDE COMMUNICATIONS RELAY SATELLITE
- PROVIDE 1,000 FT/SEC ΔV CAPABILITY, PLUS OTHER NECESSARY SELF-SUPPORT FUNCTIONS, ON CREW COMPARTMENTS MOUNTED ON A PTV
- RESCUE CAPABILITY FROM EARTH VICINITY IS REQUIRED

RECOMMENDATIONS FOR STUDY AND TECHNOLOGY DEVELOPMENT

The chart lists areas where additional study and technology development would result in major contributions to the safety of advanced lunar exploration.

STUDY & TECHNOLOGY DEVELOPMENT RECOMMENDATIONS

LOCKHEED

- STUDY PROBABILITY OF OCCURRENCE OF HAZARDS IDENTIFIED
- CONTINUE SAFETY STUDIES AS IPP DEVELOPS
- STUDY AND DEVELOP MEANS FOR ARRESTING ANGULAR MOTION
- STUDY AND DEVELOP MEANS FOR CAPTURING AND DISPOSING OF DERELICT VEHICLES AND DEBRIS
- PERFORM ADDITIONAL STUDY OF PROPELLANT DEPOTS
- IMPROVE THE LUNAR METEOROID MODEL
- DEVELOP SURFACE CAVITY DETECTORS
- PREPARE A "MOON EXPLORERS GUIDE"

STUDY & TECHNOLOGY DEVELOPMENT RECOMMENDATIONS (Cont)

LOCKHEED

- DEVELOP A PRESSURE SUIT REPAIR KIT
- DEVELOP INTEGRATED SUIT/BACK-PACK WITH BUDDY-SHARING CAPABILITY AND IMPROVED MOBILITY
- DEVELOP A CLOSED LOOP BACK-PACK FOR 48 HR LIFE AT 1,000 BTU/HR
- DEVELOP BACK-PACK SWITCHING AIDS FOR EMERGENCY USE
- DEVELOP SAFE MEANS TO OPEN FACE MASKS TO RENDER AID
- DEVELOP EMERGENCY PRESSURE GARMENT WITH 5-SEC DON TIME
- DEVELOP A PORTABLE AIRLOCK
- STUDY MEANS FOR ORIGINATING LUNAR RESCUE FROM EARTH VICINITY
- STUDY APPLICATION OF RESULTS TO APOLLO/SKYLAB